AD-A264 868

Technical Report 973

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# Development and Application of a New Approach for Classifying Errors Made in Receiving Morse Code

Richard P. Kern
U.S. Army Research Institute

March 1993



United States Army Research Institute
for the Behavioral and Social Sciences



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| REPORT DOCUMENTATION PAGE | Form Approved<br>OMB No. 0704-0188 |
|---|---|

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**1. AGENCY USE ONLY** *(Leave blank)*

**2. REPORT DATE**
1993, March

**3. REPORT TYPE AND DATES COVERED**
Interim Jun 90 - Mar 92

**4. TITLE AND SUBTITLE**
Development and Application of a New Approach for Classifying Errors Made in Receiving Morse Code

**5. FUNDING NUMBERS**
62785A
791
3302
H01

**6. AUTHOR(S)**
Kern, Richard P.

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**
U.S. Army Research Institute for the Behavioral and Social Sciences
ATTN: PERI-II
5001 Eisenhower Avenue
Alexandria, VA 22333-5600

**8. PERFORMING ORGANIZATION REPORT NUMBER**
ARI Technical Report 973

**9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)**
--

**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**
--

**11. SUPPLEMENTARY NOTES**
--

**12a. DISTRIBUTION/AVAILABILITY STATEMENT**
Approved for public release;
distribution is unlimited.

**12b. DISTRIBUTION CODE**
--

**13. ABSTRACT** *(Maximum 200 words)*


This report represents one phase of research conducted by the U.S. Army Research Institute for the Behavioral and Social Sciences on improving Morse Code acquisition skills of military Morse Code interceptors. This Morse Code training study is the first to examine performance in copying code based on response times and accuracy. For this phase of the research, a method was developed for classifying errors based on auditory characteristics of the code signals. This classification scheme was then applied to explore variations in error pattern as an indicator of slow training progress.


**14. SUBJECT TERMS**
International Morse Code
Morse Code training
Ability groups
Auditory-perceptual processes
Training process

**15. NUMBER OF PAGES**
71

**16. PRICE CODE**
--

| 17. SECURITY CLASSIFICATION OF REPORT | 18. SECURITY CLASSIFICATION OF THIS PAGE | 19. SECURITY CLASSIFICATION OF ABSTRACT | 20. LIMITATION OF ABSTRACT |
|---|---|---|---|
| Unclassified | Unclassified | Unclassified | Unlimited |

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

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# Development and Application of a New Approach for Classifying Errors Made in Receiving Morse Code

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**March 1993**

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**Army Project Number**
**2Q162785A791**

**Manpower, Personnel, and Training**

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## FOREWORD

The training of personnel to receive International Morse Code transmitted at high speeds has been plagued with high attrition rates. Focusing on this problem, the U.S. Army Training and Doctrine Command (TRADOC) requested that the U.S. Army Research Institute for the Behavioral and Social Sciences (ARI) undertake a comprehensive research program to assist the U.S. Army Intelligence School-Fort Devens (USAIS-D) in reducing attrition in their Morse Code Interceptor training program. This Morse Code training research is the first to examine performance in copying code based on response times and accuracy. This report represents one phase of the research program. This phase developed a method for classifying errors based on auditory characteristics of the code signals. It then applied this classification scheme to explore variations in error patterns as an indicator of slow training progress.

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## ACKNOWLEDGMENTS

I wish to thank Paul J. Tremont for undertaking and diligently accomplishing the major share of the U.S. Army Research Institute for the Behavioral and Social Sciences (ARI) work in collecting Morse Code copying data from trainees at the U.S. Army Intelligence School-Fort Devens (USAIS-D). I also wish to thank the Director and staff of the Directorate of Evaluation and Standardization (DOES), with special thanks to Richard Hagerdon for making this data collection possible.

Special thanks are due Hillel Sukenik, U.S. Army Information System Command-U.S. Army Research Institute (USAISC-ARI) for the programs that allowed collection of code copying data and response times. Special thanks are also due Nani Medici for writing the programs needed for classifying and summarizing types of errors made in the 542,000 characters sent during the ARI-conducted sessions.

DEVELOPMENT AND APPLICATION OF A NEW APPROACH FOR CLASSIFYING ERRORS MADE IN RECEIVING MORSE CODE

## EXECUTIVE SUMMARY


Requirement:

This report represents one phase of research conducted by the U.S. Army Research Institute for the Behavioral and Social Sciences (ARI) on approaches to reducing attrition of Morse Code Interceptor trainees during training at the U.S. Army Intelligence School-Fort Devens (USAIS-D). The objective of this phase of the research was to develop a method for classifying errors that focused on auditory characteristics of the code signals. This classification scheme could then be used to explore variations in error patterns as an indicator of slow training progress.

Procedure:

Based on a review of Morse Code research literature, a method was developed for classifying errors based on auditory characteristics of the code signals. This method of classification was applied to explore the relationships among types of code-receiving errors, accuracy, and response time, and these relationships with rate of progress through the speed-building phase of training.

Volunteers to serve in ARI research sessions were recruited from trainees enrolled in Basic Morse Code training. Forty-six trainees served in a total of 542 sessions extending from 6 to 20 groups per minute (gpm) speed levels. Trainees who successfully completed the course were classified into three ability groups (fast, average, and slow), based on total number of days to graduate. A fourth ability group (attrit) consisted of trainees who did not complete the course.

Findings:

Data from research literature and from pilot data obtained from ongoing training at USAIS-D show substitution errors characterizing the initial learning phase differ from those characterizing the speed-building phase. During initial learning, the dominant error is one in which the substituted character matches the same number of elements in the signal sent but in a different permutation (such as dit dah for dah dit). During speed building, in contrast, the dominant error stems from a mismatch in number of elements (such as dah dit for dah dit dit). Thus, with increase in gpm speed levels, trainees' ability to perceive the number of elements is impaired, especially when the signal involves a dit in first or last position.

Mean accuracy and response time for each character were classified into three levels of accuracy for each group of students. For all groups, the difference between correct and error response times tends to be largest at the highest accuracy level, with error response time the longest. There is little or no difference between response times for correct and error responses at the lowest accuracy level.

Analysis of error types for the four groups shows that the fast group is the only one in which period/no response has a frequency higher than the frequency for substitution error types at each level of accuracy and across all speed levels. Greater use of period/no response as opposed to substitution errors may reflect greater ability or skill in detecting a defective perception of the signal's pattern.

One important factor necessary for interpreting results from future research on Morse Code learning is the ability to control for cumulative training time and time in speed group for each set of data collected. In this study, we could not control for time in training or time in speed group when the trainee reported for each research session. Inability to exert this type of control during collection of data may be the major reason no clear differences were found among ability groups.

Utilization of Findings:

This research provides an empirical basis for categorizing the many errors made by students learning to copy Morse Code. The research is fundamental to efforts to model the cognitive processes of code reception and develop approaches for improving trainees' code acquisition skills, thus reducing training attrition.

DEVELOPMENT AND APPLICATION OF A NEW APPROACH FOR CLASSIFYING ERRORS MADE IN RECEIVING MORSE CODE

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# DEVELOPMENT AND APPLICATION OF A NEW APPROACH FOR CLASSIFYING ERRORS MADE IN RECEIVING MORSE CODE

## INTRODUCTION

This report describes the development and application of a method for classifying code copying errors that focuses on characteristics of the code signals as opposed to the identity of individual character confusions. The objective of this method of classification was to explore the extent to which changes in these error types reflect changing demands placed on trainees' auditory-perceptual processes as they move from initial learning through the speed building phase of training. Application to historical data obtained from the literature and pilot data obtained from current training demonstrates that the specific error types characteristic of each phase of training during the World War II era are also characteristic of each phase of current training. And finally, application was made to code receiving data obtained from 46 trainees who volunteered to participate in special sessions. Using these data, this report explores the relationships among types of code receiving errors, accuracy, and response times and the relationship of these factors to rate of progress through the speed building phase of training.

## BACKGROUND

Keller (1953) provides a succinct review of S. F. B. Morse's introduction of the first version of Morse Code in about 1838, followed by a second and finally a third version, known as American Morse Code, in about 1844. He reports that International Morse Code is a variation of American Morse that was adopted for use by the United States military prior to World War I. Taylor (1943) reports that his review of research literature on the learning of telegraphic code found only 19 articles published since the 1897 and 1899 articles by Bryan and Harter and of these, only 6 were in the English language. Those 6 articles appear to reflect work carried out in support of selection and training of telegraphers during World War I.

There have been, by my review, 64 journal articles and technical reports published in English since Taylor's review (Bibliography, Appendix A). The majority (64%) of this literature reflects work carried out during World War II on training conditions affecting the initial learning of individual characters and is reviewed by West (1955). Twenty-three percent of the 64 papers were published between 1956 and 1970. Research on Morse code training virtually disappeared during the last 20 years. Only six of the 64 papers were published from 1970 to 1990.

## Overview of the Structure of Military Code Training

Military training in receiving International Morse Code has tradionally been conducted in two phases. The first phase has been the initial learning phase. During this phase the student receives the signal for each character, one character at a time. With variations in training techniques since World War II, students have been allowed from 1.5 to 3 seconds to respond, and then were given an aural or visual representation of the correct response. Practice trials continued until the student correctly responded to each signal at some given criterion of success (e.g., 96% correct).

In current training, once the criterion for the inital learning phase has been met the student begins receiving blocks containing 50 groups composed of 5 randomly assigned characters at a speed of 6 groups per minute. This phase, called the speed building phase, progresses by gradually increasing the number of groups per minute as the student meets some criterion of correct responses (e.g., 96% correct on a 250 character block). As the number of groups per minute (the speed) is increased, the timing of each character signal [1] remains the same while the intervals between character signals and between 5 character groups are shortened. The standard used for defining timing is based on the word CODEZ. Based on this standard, the timing in msec for speed levels from 6 through 20 groups per minute (gpm) is shown in Table 1. The International Morse code for letters, numbers, and for the military's five special characters is shown in Appendix B.

## Error Performance Within the Initial Learning Phase of Training

Keller (1953) reports that until data collection on code-learning begun during World War II, the fact that some characters are harder to learn than others was not widely recognized. Research to examine

[1] Dits are always 50 msec and dahs are always 150 msec in duration. The time separation between the elements (dits, dahs) making up a character code always remains at 50 msec.

Table 1

Timing for Interval Between Characters, and Interval Between Each Five Character Group (CODEZ Standard)

| | Intervals in msec | | |
|---|---|---|---|
| Speed (gpm) | Between Characters | Between Groups | Total time per Group |
| 6 | 1260 | 2940 | 10030 |
| 8 | 860 | 2008 | 7498 |
| 10 | 624 | 1455 | 6001 |
| 12 | 466 | 1087 | 5001 |
| 14 | 353 | 824 | 4286 |
| 16 | 268 | 626 | 3748 |
| 18 | 203 | 473 | 3335 |
| 20 | 150 | 350 | 3000 |

this question was undertaken by a number of researchers during the early 1940s. Of interest here are three reports which contained detailed data on errors and omissions made for each character during the initial learning phase (Keller & Taubman, 1943; Plotkin, 1943; Spragg, 1943) and one report which provided similar data for four successive stages during the speed building phase (Seashore & Kurtz, 1944).

The 3 initial learning studies were all conducted by presenting successive runs of 100 randomly sequenced code signals following Keller's code-voice method (1943). This method presents a signal to which the student has 3 seconds to respond before the tape or the instructor announces the correct phonetic name of the signal. Using a special answer sheet containing double rows of boxes, the students recorded their responses in the top row of boxes and, if incorrect, they entered the correct responses in the boxes directly below their responses. All characters were presented in each run. Plotkin's data is based on the number of times a signal was responded to correctly until the criterion of 3 successive correct responses was made to that signal. Keller and Taubman, on the other hand, used the criterion of 95% correct in 3 successive 100 character runs. They defined difficulty level as the number of incorrect responses made per character until the criterion was reached.

Thirty-six characters (26 letters and 10 numbers) were trained by Keller and Taubman and by Plotkin. Plotkin (1944) reported a correlation of .94 between the relative difficulty level of the 36 characters in his study with those in the Keller and Taubman study.

Spragg (1943) used the same training procedure reported by Keller and Taubman and by Plotkin. However, Spragg trained on only the 26 letters and to a proficiency of 95% correct on the first 100 signal run. Spragg used the same definition of difficulty level as that used by Keller and Taubman. He deleted number characters from Keller's and Taubman's rank ordering and obtained a rank-difference correlation of .91 between the order of difficulty of letters he obtained and those obtained by Keller and Taubman. Applying the same procedure to Plotkin's data, I obtained a rank-order correlation of .96 between Plotkin's and Spragg's rank ordering of letters.

Westerman and Ramsay (1990) reported a study of initial learning based on nine volunteer staff members of the US Army Research Institute (ARI). These subjects all successfully met the criterion of two successive errorless runs of the 26 letter codes. Order of difficulty of letters for these subjects correlated in the seventies and eighties with data from each of the three early studies cited above.

Thus, during initial learning conditions, there was strong agreement on the ordering of characters from relatively difficult to relatively easy to learn.

## Error Performance Within the Speed-Building Phase of Training

The scope of the four studies cited above did not include performance during the speed building phase. However, Seashore and Kurtz (1944) tested large numbers of military trainees in several different schools at the end of the 2nd, 4th, 8th, and 12th week of training. Tests used were the Code Receiving Tests developed by the Radio Code Research Project. Trainees in the 2nd and 4th week groups received the 4 gpm test while those in the 8th and 12th week were tested on the highest speed they had passed. Tests used with these trainees ranged from 6 to 18 gpm. Data used to establish the relative difficulty level of characters was based on individuals in the 2nd and 4th week who scored at or above 80% correct and in the 8th and 12th week who scored at or above 90% correct. Errors were tallied across all speed groups tested and were not reported by each speed group level. They report that the relative difficulty level of characters (mixed alphabet and numbers) were highly correlated across the 4 successive week intervals of speed building (range .86 to .97). In addition, difficulty level of characters correlated highly across schools (range .89 to .95).

Thus, during speed building there was strong agreement on the rank ordering of characters for difficulty level.

Changes in Error Performance Across Phases of Training

In summary, under the training conditions used in the studies cited above, characters ordered by difficulty level of learning form a particular hard-to-easy ordering that can be said to characterize the initial learning phase. By the same token, the Seashore and Kurtz study found a particular ordering of character error rates during speed building that could be said to characterize the speed building phase. If characters which are hard to learn during initial learning are also those with high error rates during speed building, then it suggests that those characters were not adquately learned during initial learning. If, on the other hand, there is zero relationship between the ordering characteristic of the two phases, then it suggests that the ongoing stream of five character groups, and with increasing speeds, introduces auditory-perceptual processes not required during initial learning.

The Seashore and Kurtz (1944) study provided the only published data I found that enables an examination of the extent of agreement between relative difficulty of characters during initial learning and character error rates during speed building. I computed correlations between the difficulty level of the 36 characters reported from the initial learning studies of Keller & Taubman (1943) and of Plotkin (1943) with character error rates Seashore & Kurtz obtained at the ends of the 2nd and 12th weeks of speed building. Difficulty levels from initial learning versus character error rates at the end of the 2nd week correlated .26 and .21, respectively. However, the correlations between character difficulty levels from initial learning and error rates obtained at the end of the 12th week of speed building were .05 and -.01, respectively.

In considering the low and zero correlations, it is important to keep in mind the underlying differences in the error rates for these two different phases of training. As Seashore and Kurtz (1944) point out, the relative difficulty levels computed for initial learning reflect the accumulated errors the student makes, starting from complete ignorance of the codes to the time the student is able to meet the accuracy criterion for the set of 36 characters. Upon entering speed building, the student has presumably mastered the recognition of characters sent one at a time and is now required to recognize and copy them under increasingly stringent time restrictions.

The change in relative difficulty level of characters from initial learning conditions to speed building underlines the existence of different perceptual requirements imposed by the two phases. The presence of a relationship between the relative difficulty of characters during initial learning conditions and early (2nd and 4th week) speed building conditions is probably due to the 4 gpm speed test used. At this speed, the trainee would have approximately a 2-second gap between each character in the five character group. This is only 1 second shorter than the time allowed in initial training. Note that this relationship disappears by the end of the 12th week when speed group tests used were matched with the highest speed group the trainee had passed. These tests ranged from 6 to 18 gpm.

## DEVELOPMENT OF A FRAMEWORK FOR CLASSIFYING ERRORS

### Error Types That Change With Phase of Training

The earlier studies that have offered various ways of classifying errors have focused on errors produced in initial learning (e.g., Plotkin, Spragg) or those produced during speed building (Seashore & Kurtz). However, the lack of agreement between these two phases means these classifications are only addressing stages of a learning process and do not address how the learning process develops throughout the two phases.

As characters are transmitted at increasing speeds, one might expect that this makes increased demands on the trainees' auditory-perceptual processes and is likely to result in shifts in types of errors. A method of classifying errors is needed that shifts focus from individual character confusions to characteristics of the signals that may have implications for the requirements placed on the students' auditory-perceptual processes.

The character sent and error couplets reported by Spragg (1943), Keller and Taubman (1943), and Plotkin (1943) differed in features when those with high error rates were compared with those with low error rates. The most prominent feature of substitution errors for characters having high error rates during initial learning is that they correctly match the number of elements [2] in the signals sent (Spragg, 1943). It is interesting to note that in a study conducted by Rothkopf (1957) similar results were obtained when subjects were not trained to identify codes but simply made "same" or "different" judgment when presented with pairs.

A major feature of substitution errors during the speed building phase deals with the "signal shrinkage phenomenon" (Seashore & Kurtz, 1943). Keller (1953) in discussing this phenomenon cites research on accuracy in judging number of clicks, short tones or dots performed by Hall & Jastrow (1886), Taubman (1944, 1950), Garner (1951), and an unpublished 1943 study by Jerome. In general, these studies all found that the most frequent errors of judgment are underestimation of number of sounds. Accuracy fell off markedly as the number of sounds increased or as the number sent per time unit increased.

Shepard (1963) analyzed error data from the same studies conducted by Rothkopf, Keller and Taubman, Plotkin, and Seashore and Kurtz that have been cited above. He reported a shift in error types from initial learning to speed building consistent with those described above as different major features of the two phases.

<u>A First Step in Classifying Substitution Errors</u>

A framework for classifying all possible substitution errors was developed by first classifying errors based on whether the number of elements in the error character matched or mismatched the number of elements in the signal sent. The possible number of match and mismatch errors for the 36 signals used by Plotkin and by Seashore and Kurtz is shown in Table 2.

[2] Elements are the dits/dahs making up a character's signal.

Table 2

Classification of All Possible Matching and Mismatching Errors for Letters and Numbers

Signals Classified: 26 letters and 10 numerals

| | Number of signal - error response pairs |
|---|---|
| Match number of elements: | 146 (with permutations = 292) |
| Mismatch number of elements: | 484 (with permutations = 968) |

Using this classification, the error data reported by Plotkin (1943) for initial learning and the data reported by Seashore and Kurtz (1944) for speed building are shown in Figure 1. This figure shows a lower relative frequency of mismatch errors with a higher

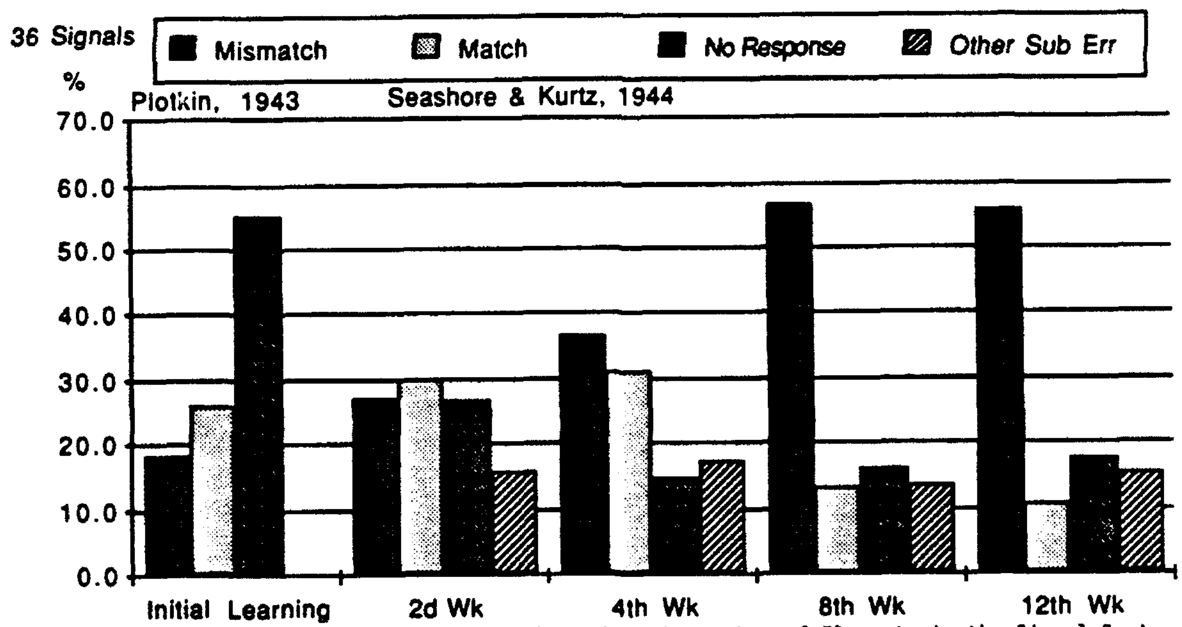


Figure 1. Errors That Mismatched and Matched the Number of Elements in the Signal Sent. (Percent of All Errors)

relative frequency of matching errors during initial learning. The relative frequency of these two types of errors is then reversed during speed building. The "other sub errors" shown in Figure 1 represent character errors that, unfortunately for present purposes, Seashore and Kurtz did not identify. They considered these unimportant for attention in remedial instruction because they were widely distributed errors that represented less than 10% of the errors for each signal sent.

Plotkin as well as Seashore and Kurtz randomly mixed numerals with letters. This practice greatly expands the possible number of errors that mismatch the number of elements in the signal sent. This is because all numerals have five elements while the 26 letters range from one to four elements. The possible number of match and mismatch errors when only the 26 letters are sent is shown in Table 3.

Current training does not randomly mix numerals with letters. An effort was made to estimate what the relative proportion of match and mismatch errors would be if only the signals for letters had been sent. The data in Figure 2 was obtained by removing all errors involving numerals. This suggests that if numerals had not been mixed with letters during initial learning, the proportion of

Table 3

Classification of All Possible Matching and Mismatching Errors for the 26 Letters

Signals Classified: 26 letters only

| | Number of signal - error response pairs |
|---|---|
| Match number of elements: | 101 (with permutations = 202) |
| Mismatch number of elements: | 224 (with permutations = 448) |

substitution errors mismatching the number of elements in the signal sent would decrease relative to errors matching the number of elements. Figure 2 also suggests that these proportions are reversed during the 8th and 12th week of speed building even with the reduction in the number of possible mismatching errors. However, the unidentified "other substitution errors" leaves a clear interpretation of these data in question.

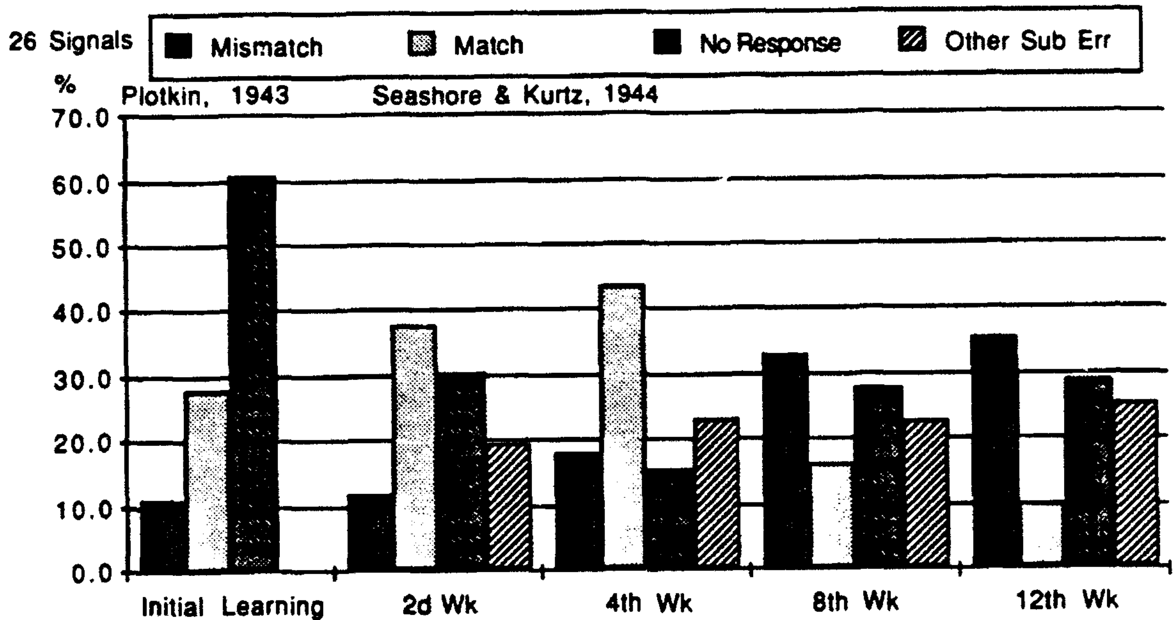


Figure 2. Changes in Type of Letter Substitution Errors at Different Stages of Training. (Percent of All Errors)

## School Training on the MCT-4 System

For approximately 20 years code training conducted at the U. S. Army Intelligence School-Fort Devens has been delivered using a computer-controlled system named the MCT-4 [3]. The student receives code signals from this system through earphones and responds using a keyboard. In addition, the student's console contains a display of the keyboard which is used to correct students' errors during initial learning by lighting the correct key on the display. During the initial learning phase code signals are sent one at a time, allowing the student 1.5 seconds to respond. If the student

[3] This system has been replaced by an updated computer system since collection of classroom data contained in this report. Unlike the MCT-4, this new system scores and displays on the student's monitor characters sent paired with the responses made at the end of each 250 character block. It is reported that attrition has dramatically decreased since the introduction of this new system. Feedback at the end of each block may well be responsible for this improved performance during training.

does not respond within this time period, or if an incorrect key is struck, the correct key on the keyboard display is lit and remains on until the student presses the correct key. The next signal is received immediately after pressing the correct key. To progress to the speed building phase the student must have no more than 7 errors out of a block of 250 characters and must have responded within the 1.5 second time limit for at least 85% of the characters.

Students enter speed building at 6 gpm and receive code for blocks of 50 five character groups. The MCT-4 presented numerals only in the 10th, 20th, 30th, 40th, and 50th groups in the sequence. The other 45 groups contained randomly assigned letters from the alphabet and the five special characters. The criterion for passing each speed group was 96% correct for a block of 50 groups. The criterion for graduation was 96% correct on two successive blocks at 20 gpm.

## Match and Mismatch Errors in Current Training

Figure 3 presents pilot data obtained on military trainees during the speed building phase at the Intelligence School, Fort Devens. During this training the 26 letters, 5 special characters, and 10 numerals are sent. The possible number of match and mismatch

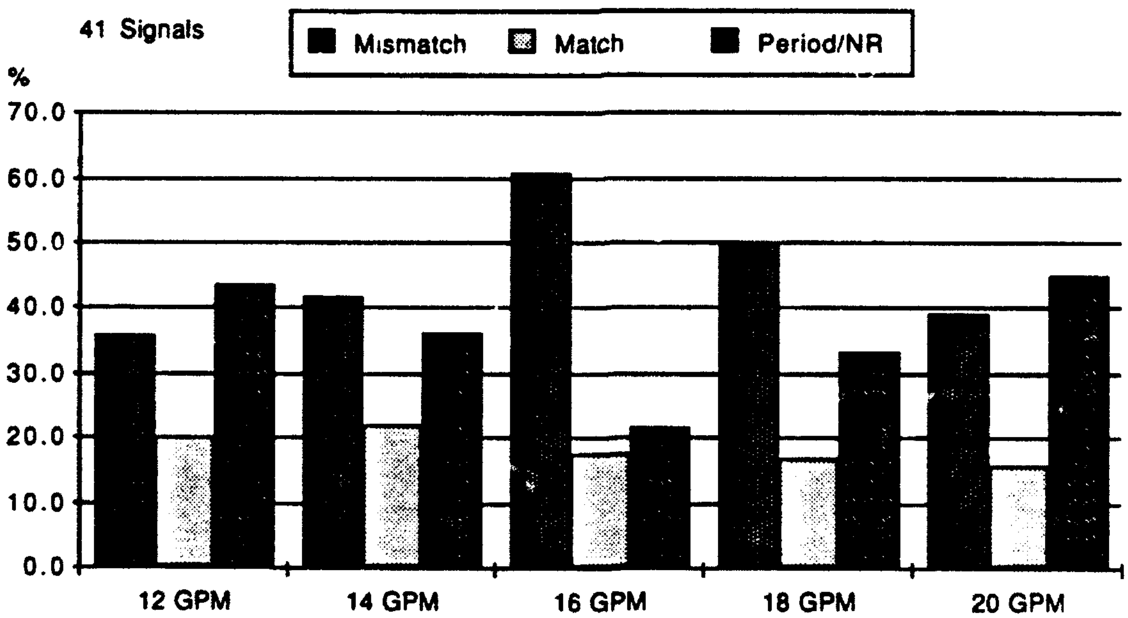


Figure 3. Three Types of Error Responses During Training on the MCT-4 Equipment. (Percent of All Errors)

errors under these conditions is shown in Table 4. However, as described above, during MCT-4 training numbers are not mixed with the other signals. As a result they are rarely confused with letters and special characters. The group per minute speeds shown in Figure 3 extend beyond the 12th week speed building period reported by Seashore and Kurtz. However, throughout these speed groups, mismatch errors represent a larger proportion of errors than do the matching element errors and are consistent with the trend in Seashore's and Kurtz's data for 26 signals (Figure 2).

Table 4

Classification of All Possible Matching or Mismatching Errors for Letters, Numbers, and Special Characters

Signals Classified: 26 letters, 10 numerals and 5 special characters used in Morse Code Interceptor Training (MCT-4 equipment)

| | Number of signal - error response pairs |
|---|---|
| Match number of elements: | 272 (with permutations = 544) |
| Mismatch number of elements: | 548 (with permutations = 1096) |

The preponderence of errors involving correctly matching the number of elements in the signal sent during initial learning suggests that with a 1.5 second interval between signals students are better able to judge number of elements than perceive the difference between dits and dahs. However, the dominant proportion of errors shifts to errors in mismatching the number of elements when receiving five character groups with decreasing time intervals between characters. That the dominance of mismatch errors persists throughout speed building (Figure 3) suggests that this may reflect an auditory-perceptual phenomenon that overrides the students' mastery of the signal-character association.

A Three-Factor Framework for Classifying Substitution Errors

To examine these errors in greater detail, each of the two classification factors, matching or mismatching the number of elements in the signal sent, was further subdivided. This subdivision was based on the difference in time durations of the signal sent and the signal incorrectly identified and, in addition, the number of elements misperceived. Time duration differences were treated as absolute numbers. Substitution errors that involve apparent misperception of two or more elements were arbitrarily defined as General Confusion (GC) errors. The resulting classification of error types is shown in Table 5 for the three conditions of signals sent shown in Table 2, 3, and 4. The character pairs classified into each of these error types are shown in Appendix C.

Distributions of these error types as percent of all errors for Plotkin's initial learning data and for data obtained from the Intellignce School-Fort Devens classrooms are shown in Table 6. The Plotkin's students received the 26 letters and 10 numerals (Table 5) while the present students training on the MCT-4 equipment received, in addition, 5 special characters (Table 5). The Fort Devens data is based on sessions that students achieved 80% or greater accuracy rates on a single block of 250 transmissions.

Note that the three Match-GC error types tend to disappear during speed building. These are errors in which the student accurately perceives the number of elements but misperceives the duration of two or more of the elements. However, while at a low relative frequency, the same can not be said of at least two of the three Mismatch-GC error types.

The Mismatch-200+ error type, among the most prominent General Confusion error during initial learning, remains at a fairly constant level across speed groups. In addition, Match-100 errors remain at essentially the same level as in intial learning. In contrast, the shifts in the relative frequency of Mismatch-100 errors from initial learning through speed building illustrate the "signal shrinkage" phenomenon.

Another error type, period/no-response is shown in Table 6. The high relative frequency during initial learning is not surprising.

Table 5

Classification of All Possible Substitution Errors for Three Different Combinations of Signals Sent

| | Number of Signals Sent [1] | | |
|---|---|---|---|
| | 36 | 26 | 41 |
| Match number of elements | Number of Pairs [2] | | |
| Match-100: 1 element incorrect | | | |
| Difference in duration: 100 msec | | | |
| (1 dit as dah or 1 dah as dit) | 44 | 34 | 59 |
| Match-General Confusion (GC): | | | |
| 2 or more elements incorrect | | | |
| Difference in duration: | | | |
| Match-GC-zero msec | 26 | 22 | 40 |
| Match-GC-100 msec | 23 | 18 | 35 |
| Match-GC-200+ msec | 53 | 27 | 76 |
| Mismatch number of elements | | | |
| Mismatch-100: 1 element incorrect | | | |
| Difference in duration: | | | |
| 100 msec (add/drop dit) | 31 | 26 | 40 |
| Mismatch-200: 1 element incorrect | | | |
| Difference in duration: | | | |
| 200 msec (add/drop dah) | 32 | 26 | 40 |
| Mismatch-General Confusion(GC): | | | |
| 2 or more elements incorrect | | | |
| Difference in duration: | | | |
| Mismatch-GC-zero msec | 49 | 26 | 66 |
| Mismatch-GC-100 msec | 69 | 30 | 92 |
| Mismatch-GC-200+ msec | 303 | 116 | 372 |

[1] 36 = 26 letters and 10 numbers; 26 = letters only; 41 = 26 letters, 10 numbers, and 5 special characters.

[2] For number with permutations, multiply by 2.

Table 6

Relative Frequency of Errors by Error Type
(Percent of All Errors)

| Error Type | Plotkin, 1943 Initial Lgn. (n=20) | Training on the MCT-4 12 gpm (n=9) | 14 gpm (n=13) | 16 gpm (n=10) | 18 gpm (n=13) | 20 gpm (n=14) |
|---|---|---|---|---|---|---|
| Match-100 | 12.5 | 9.8 | 17.3 | 13.2 | 12.6 | 14.2 |
| Match-GC-0 | 6.0 | 4.1 | 2.6 | 2.1 | 2.2 | 0.4 |
| Match-GC-100 | 3.2 | 1.6 | 0.7 | 0.9 | 0.9 | 0.1 |
| Match-GC-200+ | 4.5 | 3.5 | 1.2 | 0.8 | 1.8 | 0.6 |
| Match Subtotal | 26.2 | 19.0 | 21.8 | 17.0 | 17.5 | 15.3 |
| Mismatch-100 | 7.0 | 21.0 | 25.5 | 43.4 | 35.5 | 27.7 |
| Mismatch-200 | 2.1 | 5.5 | 7.1 | 7.1 | 5.4 | 4.8 |
| Mismatch-GC-0 | 1.7 | 1.2 | 3.0 | 2.4 | 1.7 | 2.1 |
| Mismatch-GC-100 | 2.7 | 1.8 | 1.5 | 0.9 | 0.7 | 0.7 |
| Mismatch-GC-200+ | 4.9 | 5.5 | 5.0 | 5.2 | 5.1 | 4.3 |
| Mismatch Subtotal | 18.4 | 35.0 | 42.1 | 59.0 | 48.4 | 39.6 |
| *Period/No-Response* | 55.4 | 45.8 | 35.9 | 23.9 | 34.2 | 45.0 |

However, the high relative frequency of period/no-responses throughout speed building represents a "wild card" about which one can only speculate. Seashore and Kurtz noted that at the end of the 12th week, the upper quartile of their students made more no-response errors than those in the second and third quartile. This was a reversal of what was found at the end of the 2nd week. Since copying was done by pencil, they speculate that the best students had higher rates of no response errors during the 12th week because of the difficulty of writing fast enough to keep up at the higher speed rates. Currently, copying is done using keyboards. In MCT-4 training students are taught to use the period key when they do not recognize the signal or its associated character. It is said that periods and no responses occur when students fall behind and "tune-out" briefly in order to clear memory and take a fresh start.

The classification of substitution errors and the interest in identifying changes in their relative frequency during the development of proficiency provided a framework for analyzing data obtained during the speed building phase from military Morse code training.

## ANALYSIS OF PERFORMANCE DURING THE SPEED-BUILDING PHASE

Research on performance during Morse code training was requested by the Intelligence School - Fort Devens, when attrition was running around 40%. The objective was to assist them in finding ways to reduce this attrition. The data presented below represents only an initital phase of this research. The objective of this initial phase was to develop a longitudinal data base across all speed groups. This was the first study to collect response time data. Response times as well as correct and incorrect responses to each character sent were expected to provide a much richer basis for separating those who fail to advance from those who succeed.

### Data Collection Procedures.

A code sending program was developed by ARI for delivery on Zenith 286 computers. This program was designed to send blocks of fifty character groups containing five randomly assigned letters at all *speed groups from 6 to 20 gpm.* In addition it was designed to measure response times to each character. An additional program was developed to score the students' responses and their response time to each character sent. Like the MCT-4, the initial version of this system used in collecting data for this report was not capable of scoring and displaying characters sent paired with responses made at the end of each block.

Volunteers to serve in this study were recruited from students enrolled in Basic Morse Code training. Due to the high attrition rates, students did not want to partipate in daily sessions that would take them out of classroom practice on the MCT-4 equipment. As a result, two schedules were established for obtaining twice-a-week sessions from the same individuals on a regular basis from time of initial data collection throughout the remainder of their time in speed building. One group was scheduled for two sessions a week on Tuesdays and Fridays and a second group for Mondays and Thursdays. A third group was scheduled for one session a week on Wednesdays. In each session, students received 4 blocks of 50 character groups for a total of 1000 characters. Each group contained code for 5 randomly assigned letters of the alphabet. The five special characters and the ten numbers used in the MCT-4 training were not used in this study.

Stimulus files for 72 blocks of code were designed to deliver an approximately equal number of transmissions for each of the 26 letters. These files were stored on the computer's hard disk. Students received a different set of 4 blocks in each session set at the speed level they were currently receiving in their code class.

A total of 38 students participated in the twice a week sessions with 16 participating in the once a week sessions. The number of repeated sessions and the range of speed groups obtained frcm each individual varied widely depending on a number of factors. For example, sessions at lower speed groups were not obtained for those who entered ARI sessions at 16 gpm. The number ot sessions both within and across speed groups depended on how quickly they advanced through speed groups (or, of course if they attrited). For example, with ARI sessions only once a week, faster students who were at 14 gpm, could be receiving at 18 gpm when they returned one week later.

Error Performance in ARI Sessions Compared With Regular Training

The difference in equipment and the nature of students performance in a research versus regular classroom context raised a question of whether or not performance in the ARI sessions was at all representative of their performance in the classroom. Students knew that meeting criteria for passing a speed group during the research sessions would not qualify them for passing in the classroom.

The data presented earlier on students' error performance in regular training is compared in Table 7 with data obtained from all students who participated in the research sessions. Mean errors for research sessions are based only on students who eventually passed the given speed group and who scored at least 50% correct. In Table 7 all of the General Confusion error types have been collapsed into one category. In general, the relative frequency of error types at each speed group are highly similar. The biggest differences are for mismatch-100 errors and period/no-responses at 16 and 18 gpm.

Table 7

Error Performance in Research Sessions Versus Other Students in Regular Training (MCT-4). (Percent of All Errors)

| | N | Match 100 msec | Mismatch 100 msec | Mismatch 200 msec | General Confusion | Period/NR |
|---|---|---|---|---|---|---|
| 12 gpm | | | | | | |
| Research Ss | 26 | 10.2 | 20.9 | 5.9 | 12.5 | 50.4 |
| Regular Tng | 9 | 9.8 | 21.0 | 5.5 | 17.7 | 45.8 |
| 14 gpm | | | | | | |
| Research Ss | 29 | 11.9 | 24.0 | 6.8 | 16.9 | 40.2 |
| Regular Tng | 13 | 17.3 | 25.5 | 7.1 | 14.0 | 35.9 |
| 16 gpm | | | | | | |
| Research Ss | 33 | 12.4 | 22.4 | 6.8 | 14.3 | 44.0 |
| Regular Tng | 10 | 13.2 | 43.4 | 7.1 | 12.3 | 23.9 |
| 18 gpm | | | | | | |
| Research Ss | 35 | 12.7 | 22.7 | 6.3 | 13.9 | 44.4 |
| Regular Tng | 13 | 12.6 | 35.5 | 5.4 | 12.4 | 34.2 |
| 20 gpm | | | | | | |
| Research Ss | 29 | 12.7 | 24.8 | 6.9 | 15.6 | 39.9 |
| Regular Tng | 14 | 14.2 | 27.7 | 4.8 | 8.2 | 45.0 |

Students in the research sessions tend to have higher period/no-response rates than those in regular training. Some of these students reported feeling more relaxed during the research sessions, possibly meaning less pressure to respond.

## Forming Ability Groups

The number of days it took each student to graduate from Morse code training was provided by the School's Directorate of Evaluation and Standardization (DOES). Students who graduated were classified into three ability groups based on total number of days to successfully complete code training. The range of number of days defining each group was provided by a DOES study of grouping by ability levels (Directorate of Evaluation and Standardization, 1990). These three groups, plus the group who attrited are shown in Table 8. Note that members of the latter group attrited while in speed groups ranging from 10 through 20 GPM. The difference between the total of 46 students shown in Table 8 and the 54 who volunteered is due to 8 students who dropped out after one or two sessions.

Table 8

Ability Groups Based on Performance During Basic Morse Code Training

| Group | N | Days in Training |
|---|---|---|
| Fast | 11 | 36 - 61 |
| Average | 11 | 62 - 87 |
| Slow | 13 | 88 - 155 |
| Attrit | 11 | 50 - 131 |

Table 9 shows, for each of the four groups, the number of students who participated at each speed group they eventually passed and the number of sessions they completed at the given speed group. The decrease in the number of sessions per student as one scans from the slow group to the fast group does reflect differences in number of days to pass a speed group. However, the fewer sessions in the fast group is also due to six of the eleven who were in the one session a week schedule.

Using data provided by DOES, Figure 4 shows the average number of days taken by the students in each of these four groups to pass the given speed group.

Table 9

Number of Students and Number of Sessions at Each Speed Group

| | Speed in Groups Per Minute | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 |
| Fast Grp | | | | | | | | |
| Students | 5 | 2 | 5 | 8 | 8 | 8 | 11 | 8 |
| Sessions | 5 | 3 | 7 | 9 | 16 | 12 | 17 | 22 |
| Average Grp | | | | | | | | |
| Students | 4 | 3 | 6 | 5 | 9 | 8 | 9 | 10 |
| Sessions | 4 | 3 | 9 | 7 | 12 | 18 | 25 | 54 |
| Slow Grp | | | | | | | | |
| Students | 3 | 4 | 6 | 6 | 7 | 12 | 13 | 10 |
| Sessions | 3 | 4 | 10 | 11 | 13 | 35 | 64 | 70 |
| Attrit Grp | | | | | | | | |
| Students | 5 | 6 | 8 | 7 | 5 | 5 | 2 | 0 |
| Sessions | 5 | 9 | 18 | 20 | 14 | 25 | 18 | 0 |

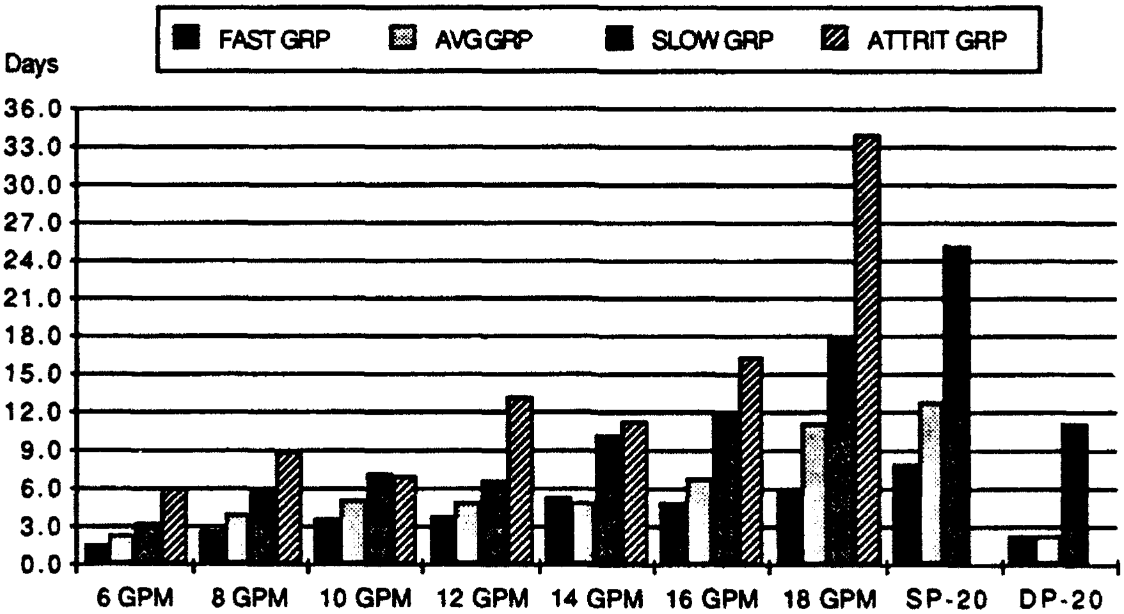


Figure 4. Number of Days to Pass Each Speed Group (SP = Single Pass; DP = Double Pass).

## PERFORMANCE BY THE FOUR GROUPS

Mean percent correct responses, mean frequency of error types, and mean response times were obtained by calculating means for each individual at each speed group. These means were based on all sessions each individual had completed within each speed group as long as the percent correct score for a session exceeded 50% correct. In addition, for members of the Attrit group, sessions at speed groups which were not passed in training were excluded. The results reported below are based on the number of students and number of sessions at each speed group shown in Table 9.

Statistical tests were not computed on any of the data reported below. Results from such tests would be misleading for two reasons. The major reason, discussed later, was our inability to control for cumulative time in training and time in a specific speed group when the student reported for each ARI session. In addition, we had intended to obtain repeated sessions across speed levels from the same students. However, we were generally unable to obtain data from the same student across more than three to four speed groups. Thus, going across speed groups we have a mixture of data from students who have and have not been present in preceding or succeeding speed groups.

### Summary Group Means for Correct Responses

Table 10 presents the mean percent correct responses for each of the 4 groups at each speed level. Inspection of this table shows a remarkable uniformity of accuracy across the 4 groups of students at each speed level. Note that the means for the Attrit group at each speed level are based only on students who successfully passed the given speed level. Thus, data summarized at this very general level does not suggest that these groups differ in performance. As long as students in the Attrit group pass a given speed level, their performance is not distinguishable from that of the other groups.

Table 11 presents the mean response times for correct responses. In general, the Fast Group tends to show the longest response times. Whether or not this trend is reliable I can not say. However, this table clearly illustrates the decrease in response times for each ability group as speed levels increase.

Table 10

Mean Percent Correct by Student Group at Each Speed Level

| | Speed in Five Character Groups Per MInute | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 6 gpm | 8 gpm | 10 gpm | 12 gpm | 14 gpm | 16 gpm | 18 gpm | 20 gpm |
| Fast Group | 81.5 | 62.8 | 75.3 | 75.3 | 73.9 | 71.0 | 70.9 | 68.4 |
| Average Group | 78.4 | 76.0 | 74.3 | 75.3 | 71.7 | 73.8 | 71.5 | 73.2 |
| Slow Group | 76.7 | 67.6 | 74.6 | 73.9 | 71.6 | 71.3 | 69.9 | 69.3 |
| Attrit Group | 82.2 | 72.4 | 71.6 | 75.6 | 73.6 | 70.8 | 76.1 | |

Table 11

Mean Response Time (msec) for Correct Responses by Student Group at Each Speed Level

| | Speed in Five Character Groups Per MInute | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 6 gpm | 8 gpm | 10 gpm | 12 gpm | 14 gpm | 16 gpm | 18 gpm | 20 gpm |
| Fast Group | 1143.1 | 999.0 | 845.1 | 785.3 | 589.8 | 592.9 | 514.6 | 460.5 |
| Average Group | 1056.6 | 841.3 | 798.4 | 604.4 | 540.4 | 457.9 | 436.8 | 406.6 |
| Slow Group | 1095.8 | 986.3 | 681.8 | 659.6 | 562.2 | 494.3 | 441.7 | 426.0 |
| Attrit Group | 1158.9 | 840.8 | 767.8 | 625.9 | 551.1 | 571.9 | 574.1 | |

## Group Means Classified Into Three Levels of Accuracy

Table 12 shows the average number of letters which received percent correct responses within each of 3 levels of accuracy. For example, for the Fast Group at 6 gpm, the group's mean percent correct for 17 of the 26 signals fell within the 81-100% range of accuracy. Note how these distributions change within each group as speed levels increase. Considering the uniformity across student groups of overall percent correct means in Table 8, it is not surprising to find a similarily high degree of uniformity across groups in this table.

Table 13 presents group mean response times for correct responses at the three levels of accuracy. Note that within each speed level, response times for the same level of accuracy are highly similar across student groups. Also note that the trend is for the highest level of accuracy to have the shortest response time and the mean response times increase as the accuracy level decreases. Thus, the longest response times for correct responses at a given speed level are generally for signals that these students seldom get correct.

Table 12

Average Number of Letters at Each of the Three Levels of Accuracy;

| | Fast Group | Average Group | Slow Group | Attrit Group |
|---|---|---|---|---|
| **6 gpm** | | | | |
| 81-100% | 17.0 | 17.0 | 12.7 | 17.0 |
| 61-80% | 6.0 | 4.5 | 10.0 | 7.4 |
| 0-60% | 3.0 | 4.5 | 3.3 | 1.6 |
| **8 gpm** | | | | |
| 81-100% | 5.5 | 13.3 | 8.3 | 11.5 |
| 61-80% | 9.0 | 7.3 | 9.8 | 8.7 |
| 0-60% | 11.5 | 5.3 | 8.0 | 5.8 |
| **10 gpm** | | | | |
| 81-100% | 11.8 | 11.5 | 12.0 | 10.0 |
| 61-80% | 10.6 | 9.2 | 9.0 | 9.4 |
| 0-60% | 3.6 | 5.3 | 5.0 | 6.6 |
| **12 gpm** | | | | |
| 81-100% | 11.8 | 10.6 | 10.8 | 13.0 |
| 61-80% | 9.9 | 12.4 | 10.5 | 7.7 |
| 0-60% | 4.4 | 3.0 | 4.7 | 5.3 |
| **14 gpm** | | | | |
| 81-100% | 10.0 | 9.7 | 10.1 | 11.4 |
| 61-80% | 11.6 | 11.1 | 10.3 | 9.4 |
| 0-60% | 4.4 | 5.2 | 5.6 | 5.2 |
| **16 gpm** | | | | |
| 81-100% | 9.0 | 10.1 | 9.3 | 8.4 |
| 61-80% | 11.4 | 11.5 | 11.7 | 10.6 |
| 0-60% | 5.6 | 4.4 | 5.0 | 7.0 |
| **18 gpm** | | | | |
| 81-100% | 7.9 | 8.6 | 7.2 | 13.5 |
| 61-80% | 12.5 | 12.3 | 13.0 | 9.0 |
| 0-60% | 5.6 | 5.1 | 6.1 | 3.5 |
| **20 gpm** | | | | |
| 81-100% | 8.5 | 11.2 | 7.5 | |
| 61-80% | 11.4 | 9.8 | 12.1 | |
| 0-60% | 6.1 | 5.0 | 6.4 | |

Table 13

Mean Response Times (msec) for Correct Responses to Characters Classified Into Three Levels of Accuracy

| | Fast Group | Average Group | Slow Group | Attrit Group |
|---|---|---|---|---|
| **6 gpm** | | | | |
| 81-100% | 1037 | 967 | 1017 | 1087 |
| 61-80% | 1263 | 1153 | 1121 | 1262 |
| 0-60% | 1494 | 1335 | 1359 | 1295 |
| **8 gpm** | | | | |
| 81-100% | 743 | 758 | 836 | 773 |
| 61-80% | 914 | 921 | 912 | 825 |
| 0-60% | 1184 | 1015 | 1255 | 959 |
| **10 gpm** | | | | |
| 81-100% | 749 | 719 | 629 | 710 |
| 61-80% | 872 | 789 | 683 | 784 |
| 0-60% | 1017 | 932 | 801 | 868 |
| **12 gpm** | | | | |
| 81-100% | 709 | 563 | 603 | 597 |
| 61-80% | 813 | 598 | 671 | 638 |
| 0-60% | 929 | 693 | 751 | 740 |
| **14 gpm** | | | | |
| 81-100% | 525 | 498 | 546 | 530 |
| 61-80% | 610 | 545 | 570 | 549 |
| 0-60% | 701 | 619 | 610 | 606 |
| **16 gpm** | | | | |
| 81-100% | 531 | 437 | 465 | 549 |
| 61-80% | 596 | 467 | 494 | 563 |
| 0-60% | 675 | 502 | 534 | 609 |
| **18 gpm** | | | | |
| 81-100% | 465 | 412 | 437 | 560 |
| 61-80% | 521 | 440 | 441 | 575 |
| 0-60% | 566 | 476 | 461 | 607 |
| **20 gpm** | | | | |
| 81-100% | 431 | 388 | 420 | |
| 61-80% | 471 | 414 | 430 | |
| 0-60% | 520 | 444 | 438 | |

Response Times Compared With Time Interval Between Letter Signals

As was shown in Table 1, speed of transmission is increased by shortening the time interval between letter signals and between 5 letter groups. Errors are frequently attributed to students attempting to respond to a letter signal before the next signal is sent. Figures 5 (6 gpm) through 12 (20 gpm) compare correct and substitution error response times for each of the four subject groups with the time interval between letter codes for each speed group.

Note that at the slowest speed, 6 gpm (Figure 5), all subject groups achieve their highest level of accuracy with responses that are made before transmission of the next signal. However, from 10 gpm (Figure 7) on, both average correct and error response times are longer than the time interval between signals at each of the three levels of accuracy. In addition, note that the difference between correct and error response times tends to be largest at the highest accuracy level (81-100%) and shows little or no difference at the lowest accuracy level (0-60%) which also tends to have the longest response times.

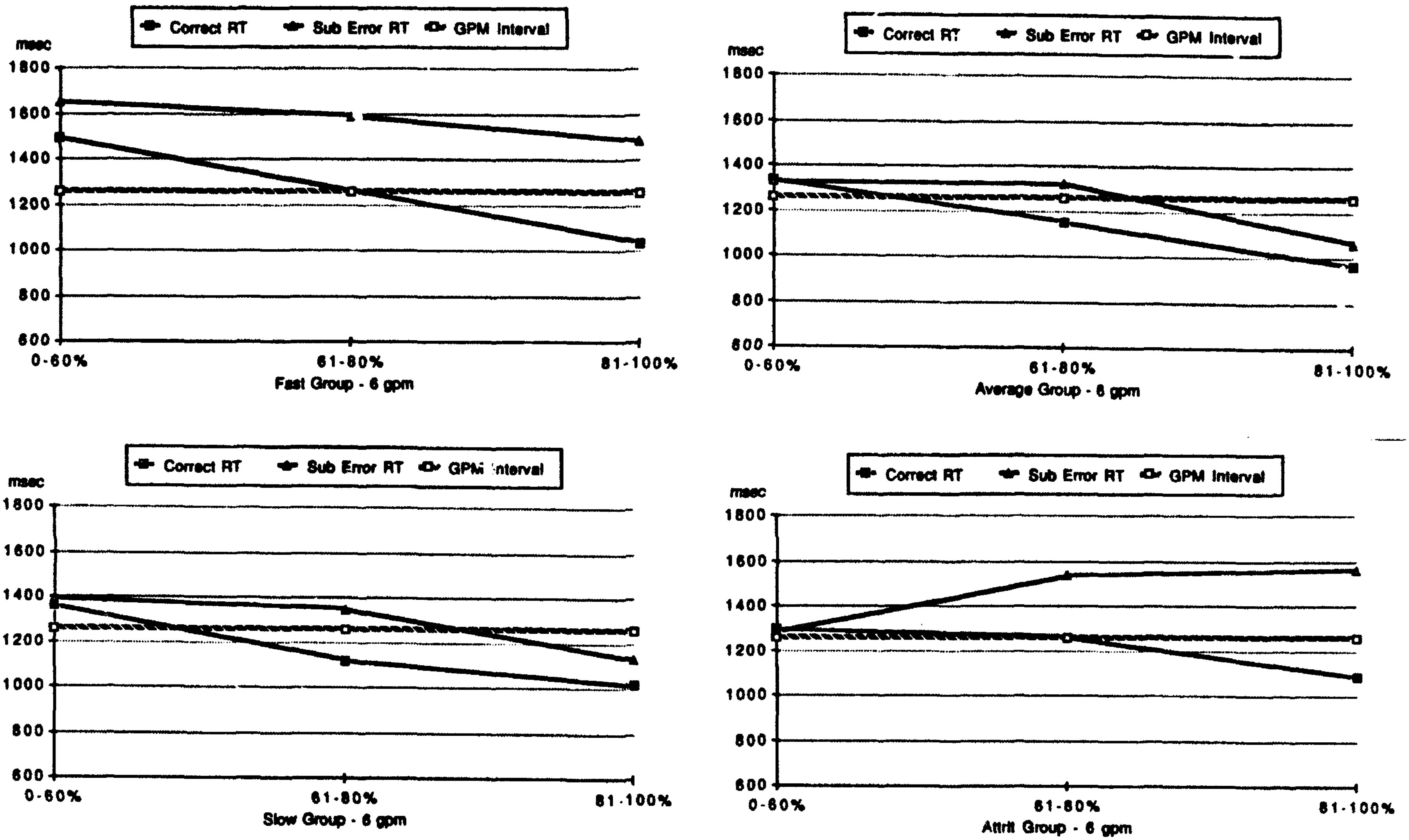


Figure 5. Mean Response Times (msec) for Correct Responses and Substitution Errors to Characters at Three Levels of Accuracy - 6 gpm

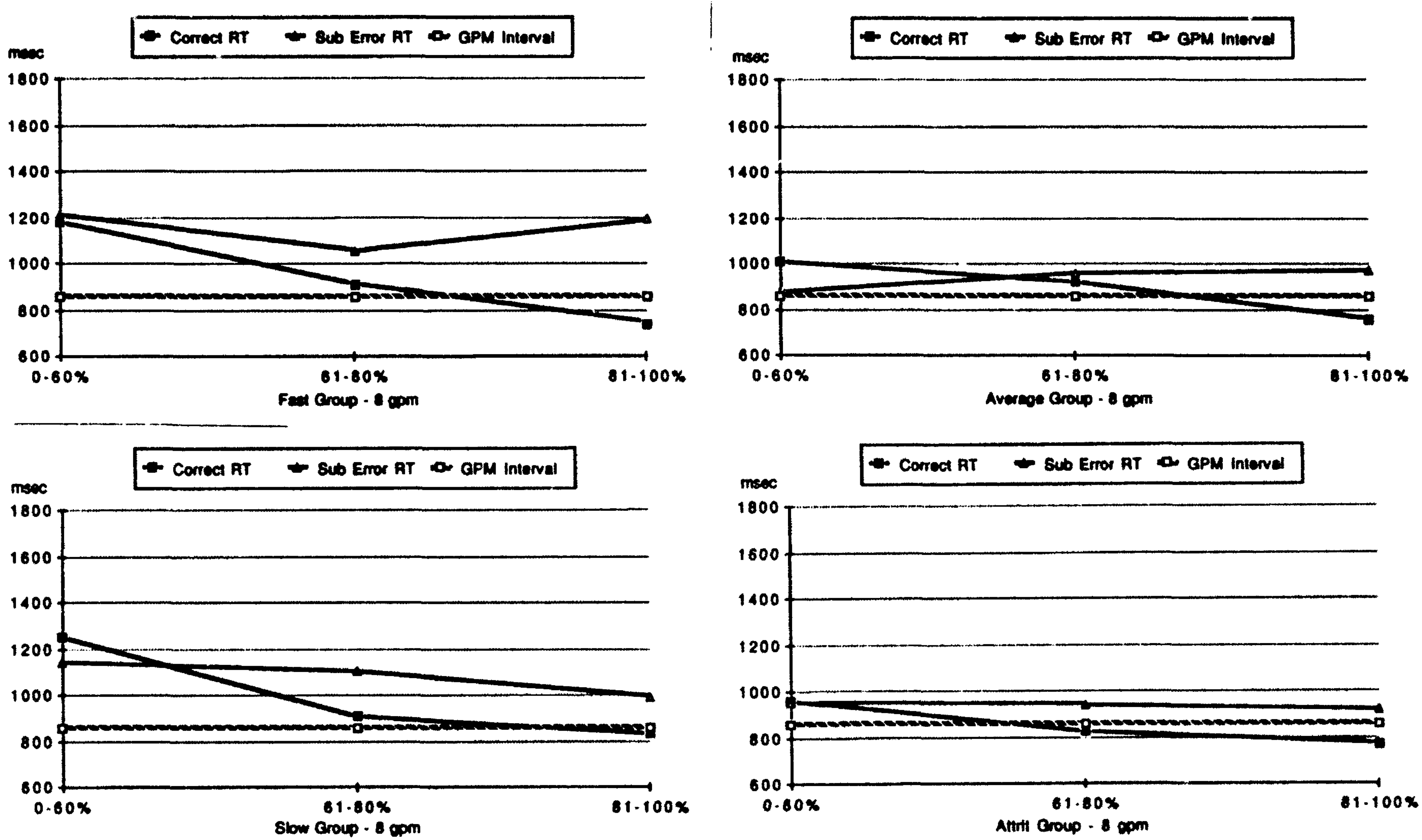


Figure 6. Mean Response Times (msec) for Correct Responses and Substitution Errors to Characters at Three Levels of Accuracy - 8 gpm

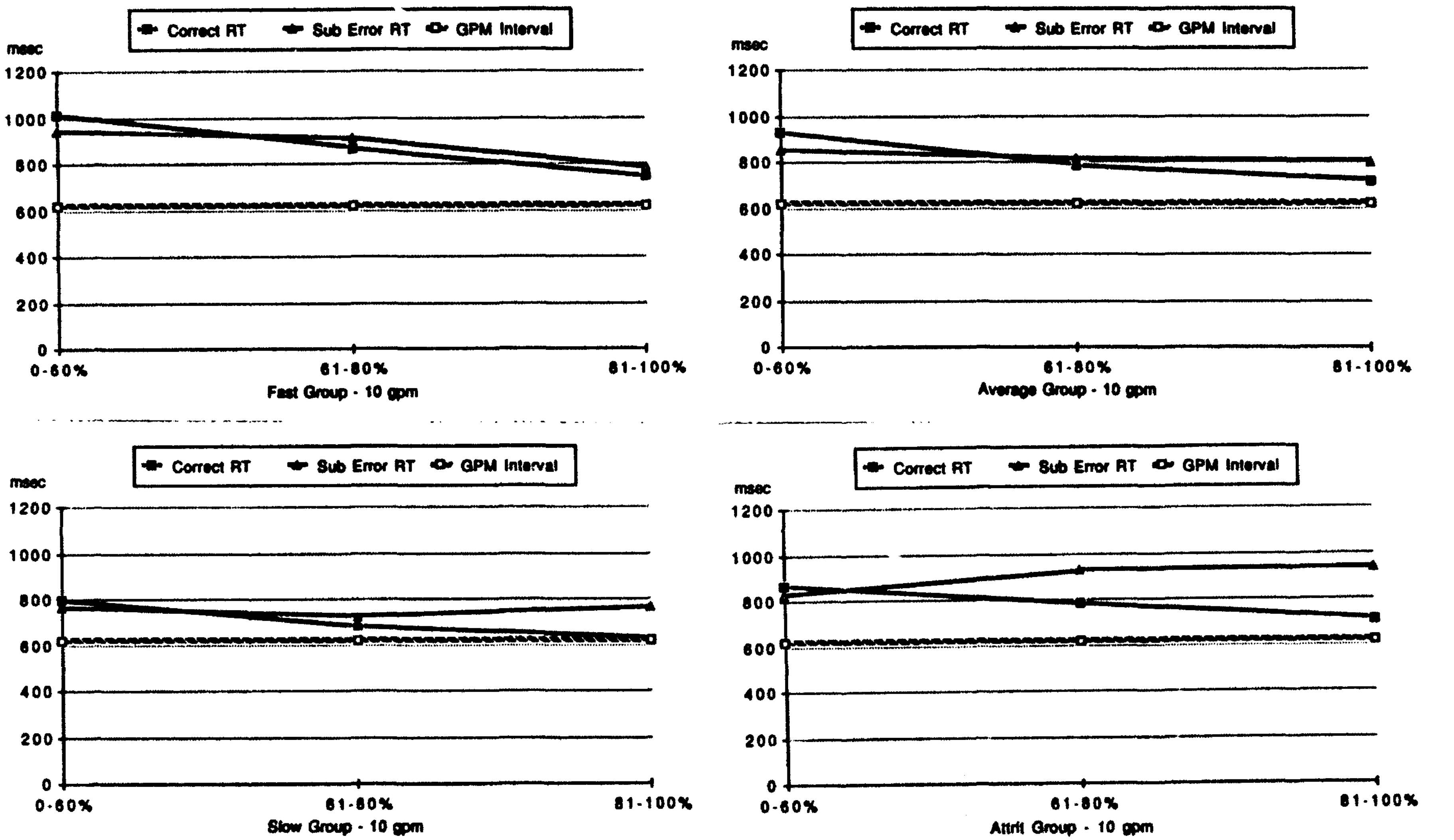


Figure 7. Mean Response Times (msec) for Correct Responses and Substitution Errors to Characters at Three Levels of Accuracy - 10 gpm

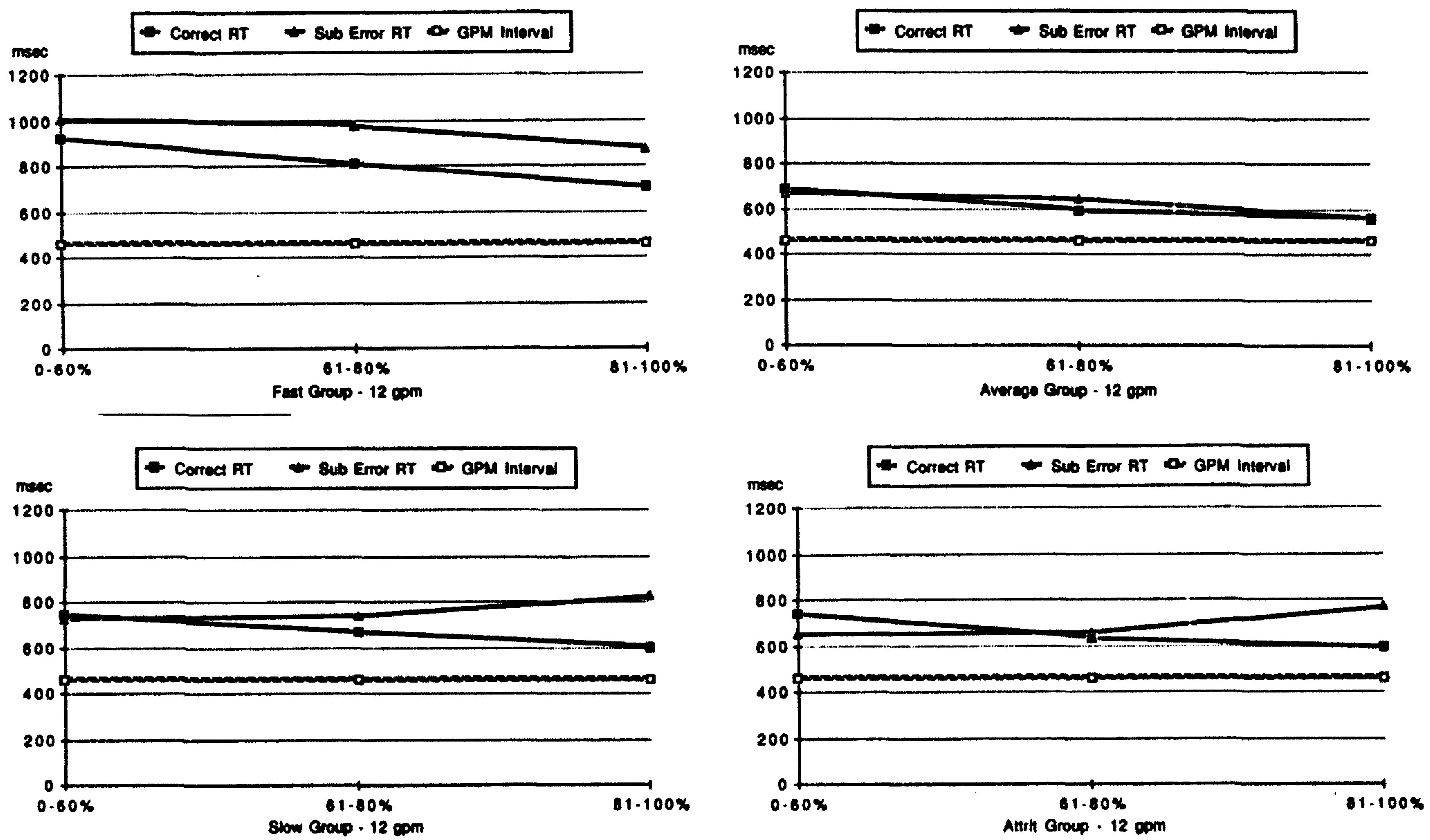


Figure 8. Mean Response Times (msec) for Correct Responses and Substitution Errors to Characters at Three Levels of Accuracy - 12 gpm

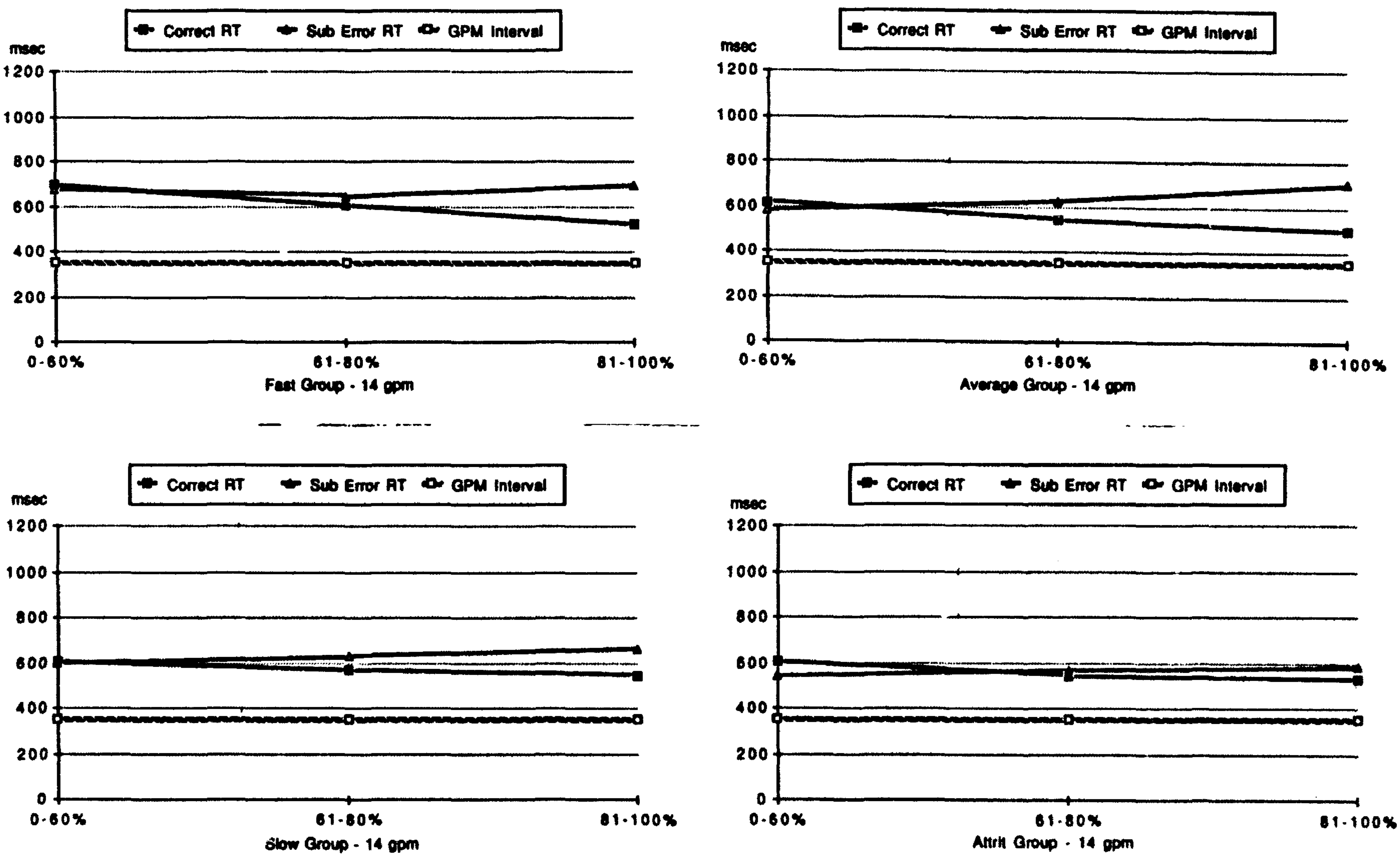


Figure 9. Mean Response Times (msec) for Correct Responses and Substitution Errors to Characters at Three Levels of Accuracy - 14 gpm

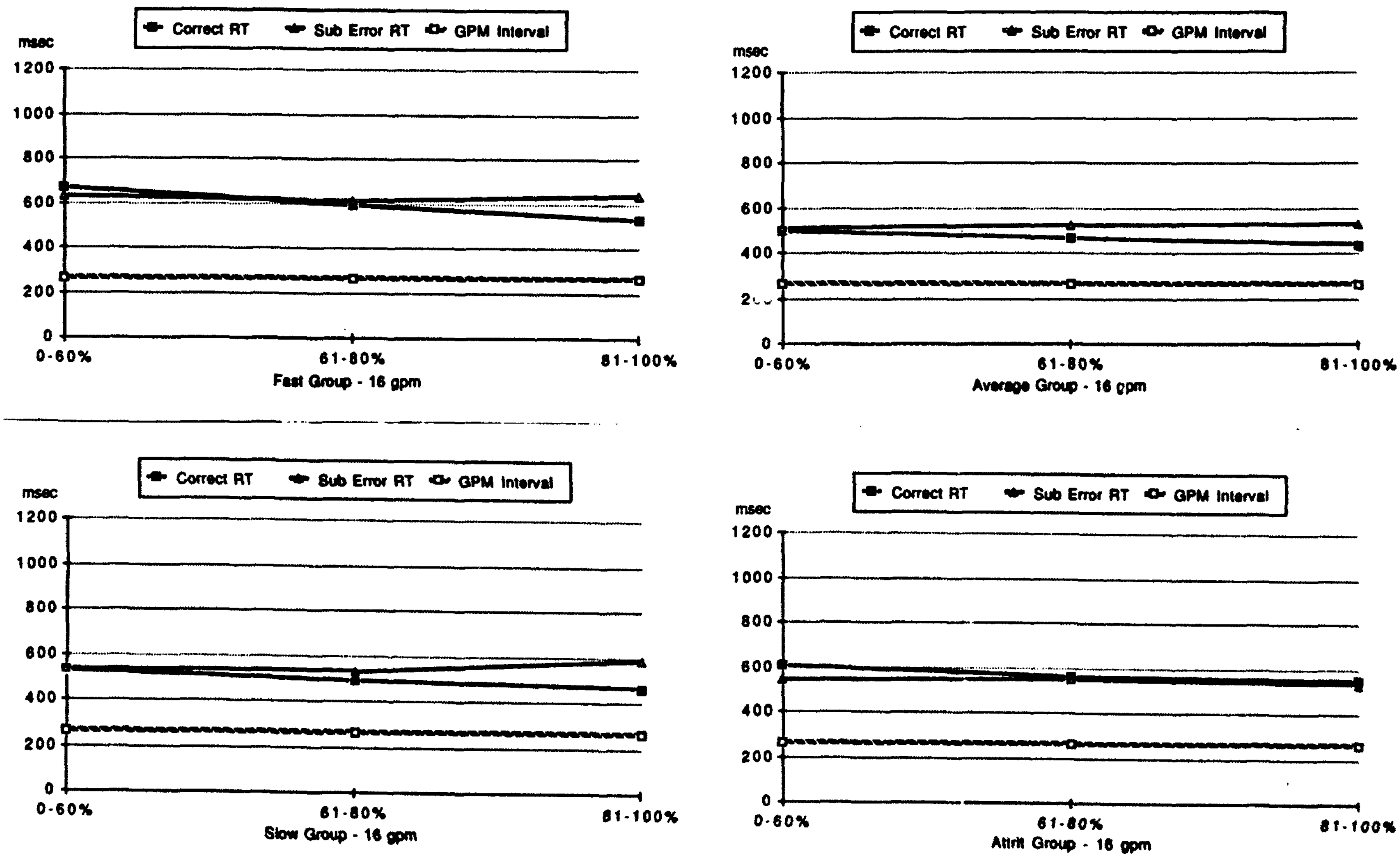


Figure 10. Mean Response Times (msec) for Correct Responses and Substitution Errors to Characters at Three Levels of Accuracy - 16 gpm

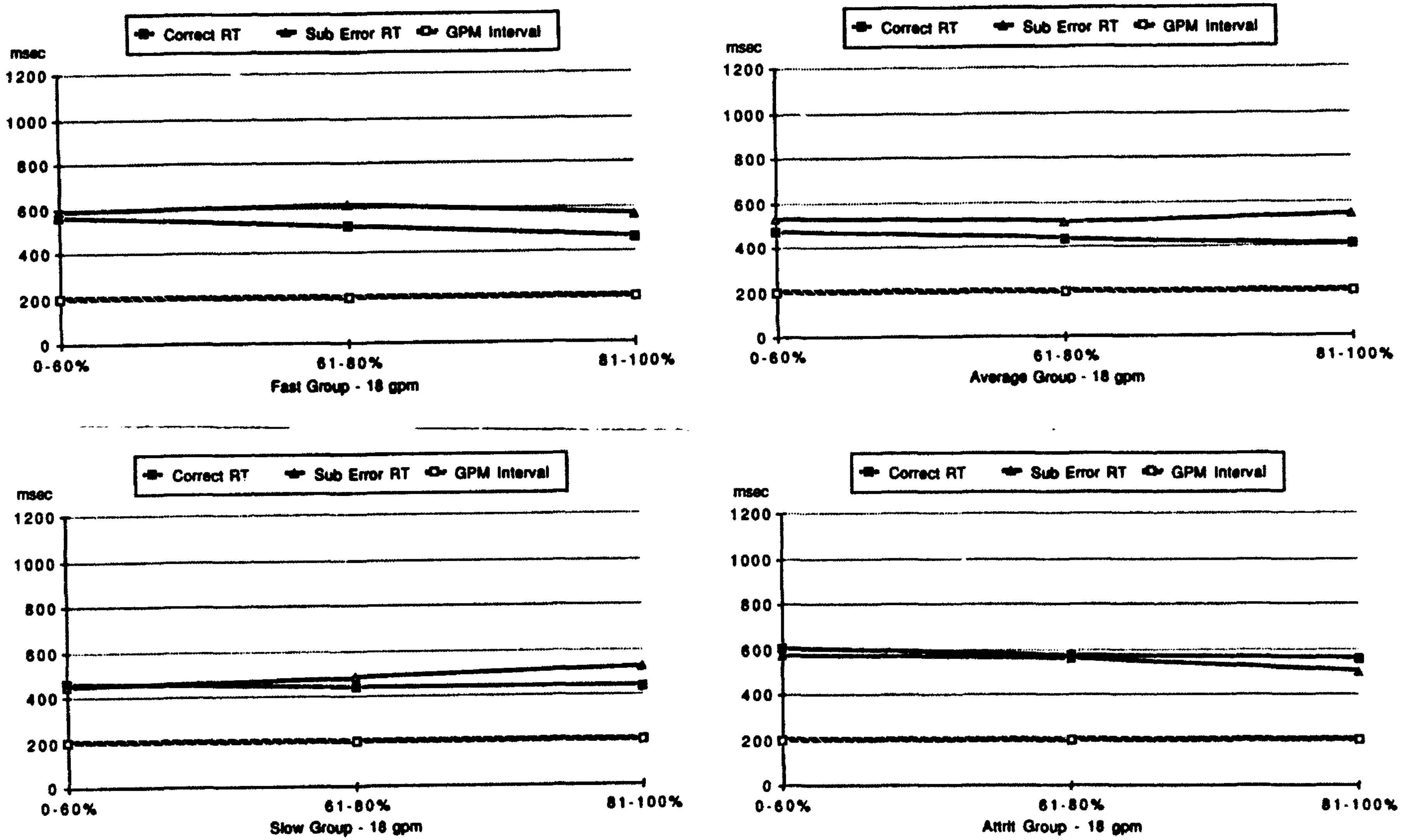


Figure 11. Mean Response Times (msec) for Correct Responses and Substitution Errors to Characters at Three Levels of Accuracy - 18 gpm

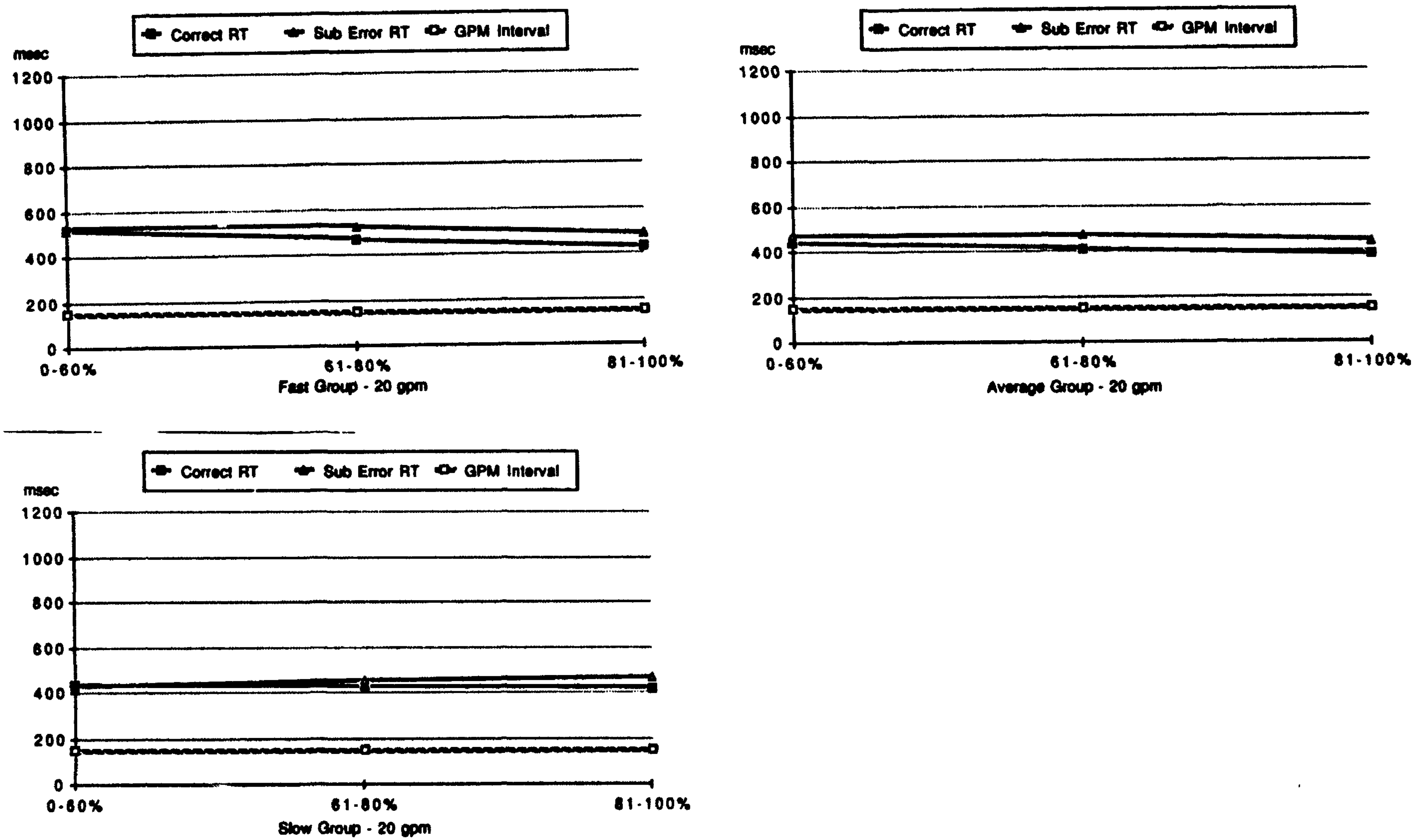


Figure 12. Mean Response Times (msec) for Correct Responses and Substitution Errors to Characters at Three Levels of Accuracy - 20 gpm

Frequency of Error Types by the Four Subject Groups

Figures 13 (6 gpm) through 20 (20 gpm) present frequency of errors for each of the five error types for the four subject groups. These frequencies represent number of errors as average percent of time each letter having the error type was sent. The # Char. column on the right hand margin of each graph simply repeats the average number of letters within each accuracy level presented earlier in Table 12. For example, in the Fast group graph in Figure 13, the average of 3 letters in the 0-60% accuracy level were responded to with period or no response about 35% of the times these letters were sent. On the other hand, the average of 17 letters in the 81-100% accuracy group were responded to with periods or no responses only about 5% of the time these letters were sent.

The Fast group is the only one of the four subject groups for which period/no response has a higher frequency than the other error types at each level of accuracy and across all speed levels. All groups show this higher relative frequency of periods or no responses to other error types at 6 gpm. However, while all four groups at 6 gpm closely match the frequency of period/no response errors at each level of accuracy, the Average, Slow, and Attrit groups also have higher rates of Mismatch-100 msec errors than the Fast group.

Starting at 8 gpm, the Average group's period/no response rate for the two highest levels of accuracy is consistently greater than the frequency of other error types across the rest of the speed levels. However, for this group at the 0-60% accuracy level, Mismatch-100 msec errors are the most frequent error type from 8 through 20 gpm.

The Slow group maintains period/no response error rates slightly higher than that of the other error types at all 3 levels of accuracy until reaching 14 gpm. From 14 gpm on the pattern is similar to that of the Average group. Period/no response rates are the highest error rates for the two highest levels of accuracy. At the 0-60% accuracy level Mismatch-100 msec errors are the most frequent error type from 14 through 20 gpm.

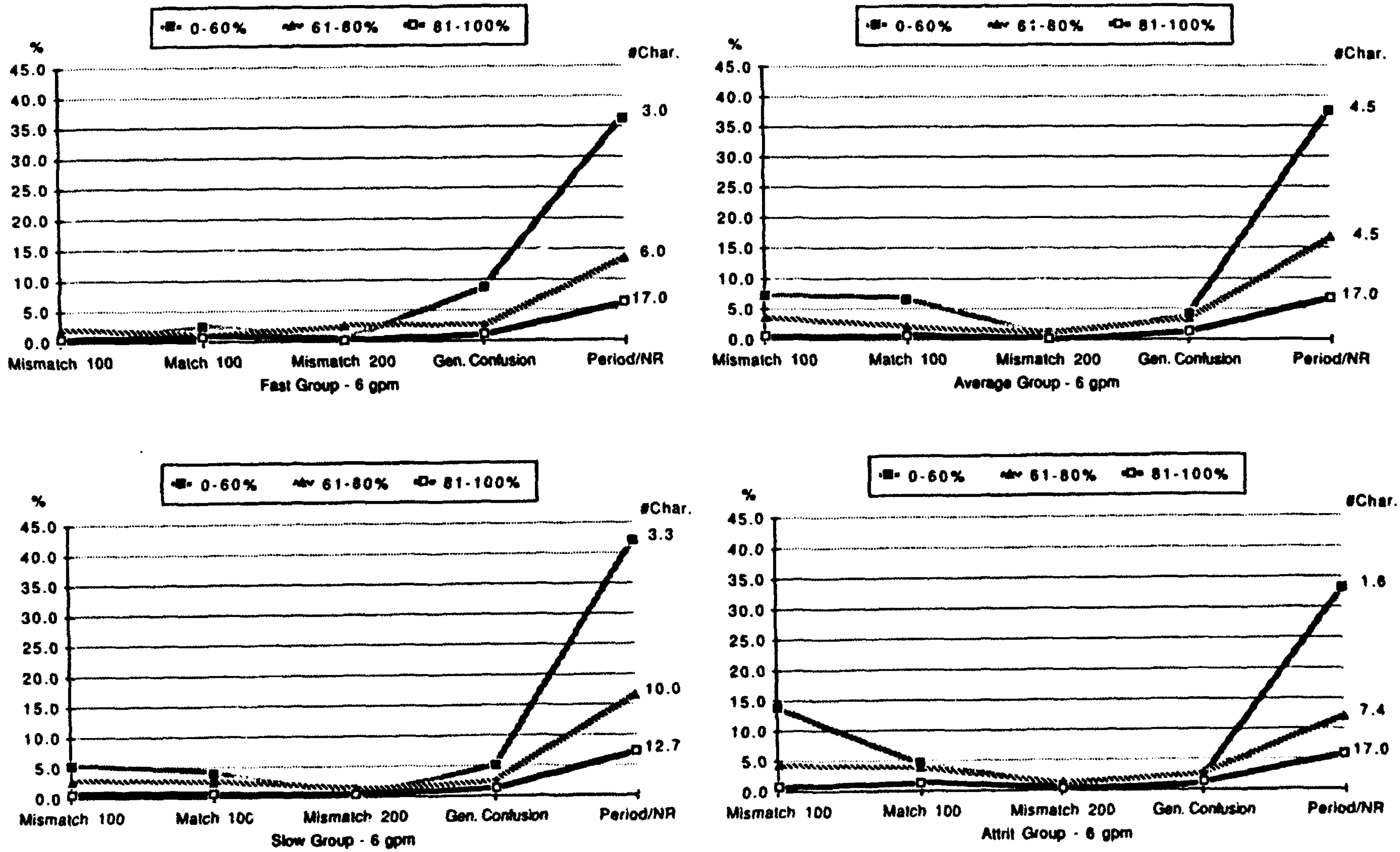


Figure 13. Frequency of Error Types Averaged Over Percent of Times Each Character Was Sent With Characters Classified Into Three Levels of Accuracy - 6 gpm .

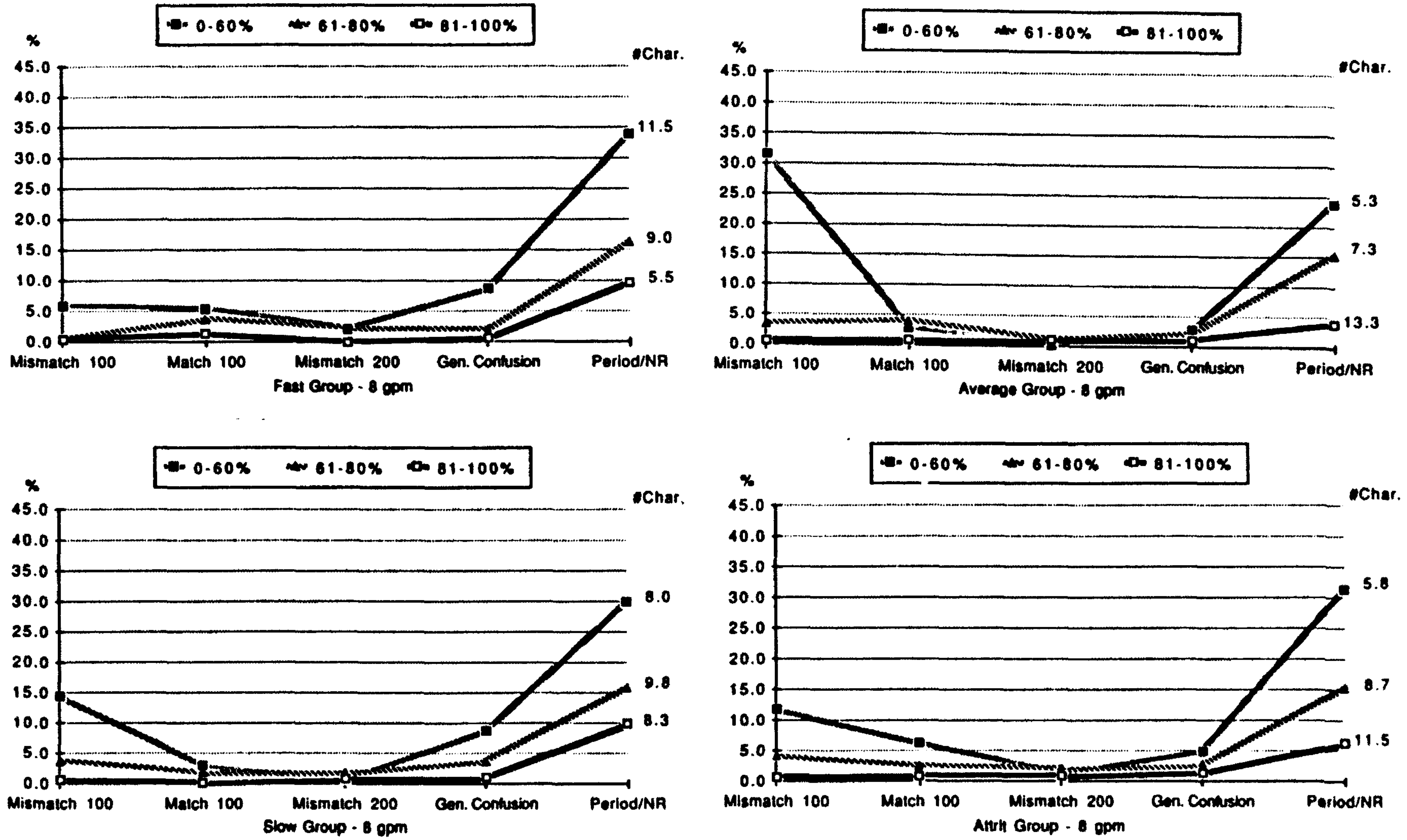


Figure 14. Frequency of Error Types Averaged Over Percent of Times Each Character Was Sent With Characters Classified Into Three Levels of Accuracy - 8 gpm

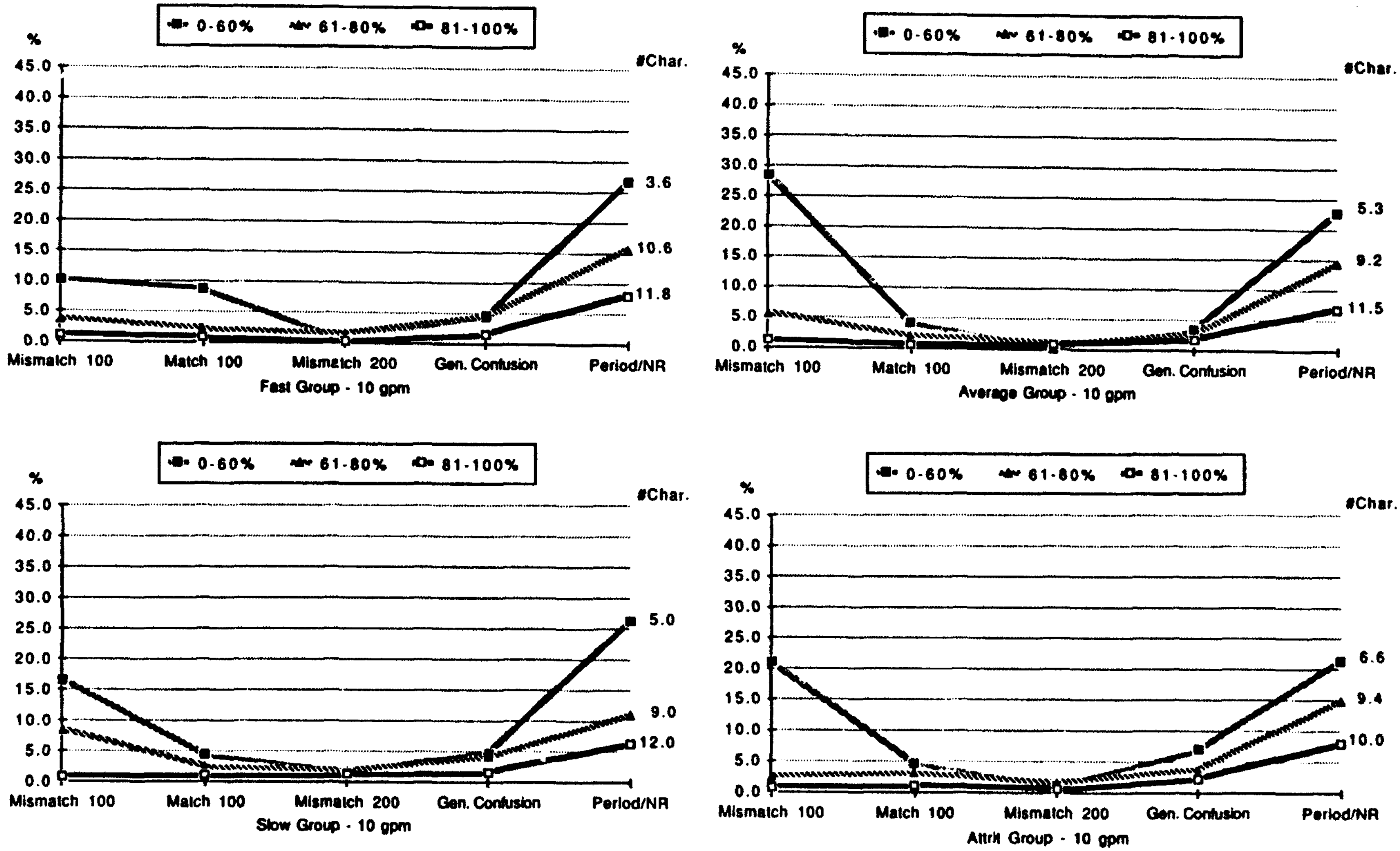


Figure 15. Frequency of Error Types Averaged Over Percent of Times Each Character Was Sent With Characters Classified Into Three Levels of Accuracy - 10 gpm

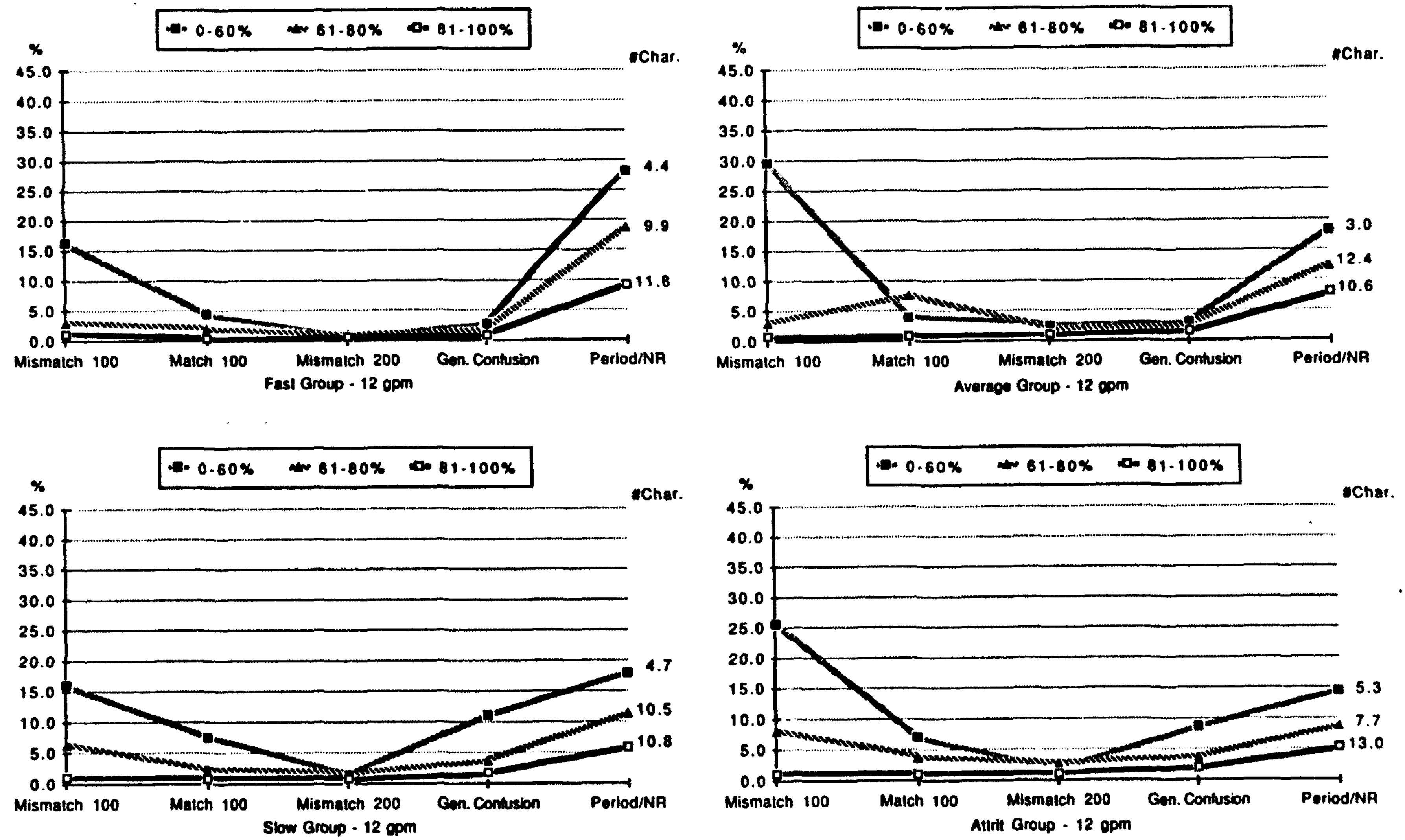


Figure 16. Frequency of Error Types Averaged Over Percent of Times Each Character Was Sent With Characters Classified into Three Levels of Accuracy - 12 gpm

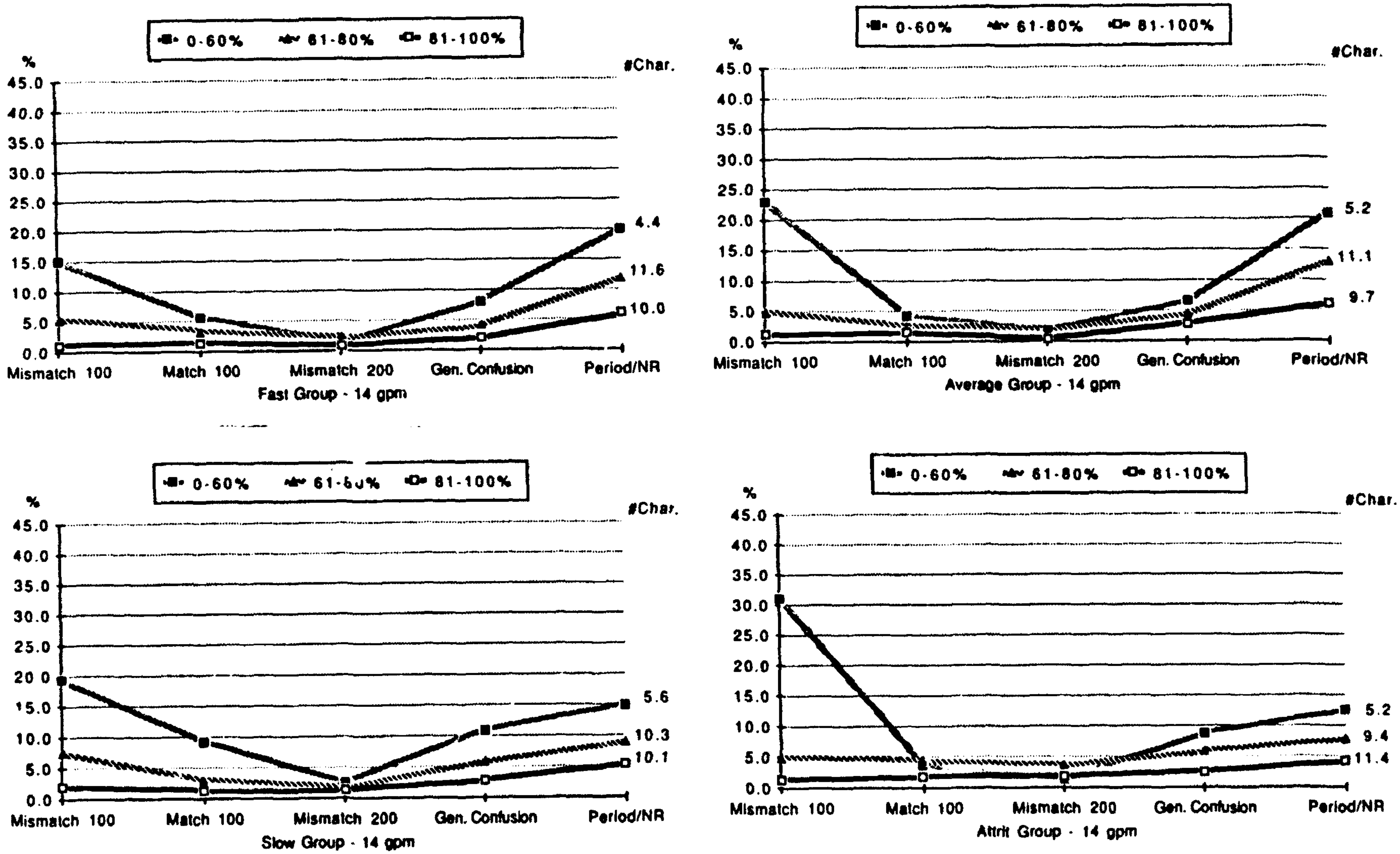


Figure 17. Frequency of Error Types Averaged Over Percent of Times Each Character Was Sent With Characters Classified Into Three Levels of Accuracy - 14 gpm

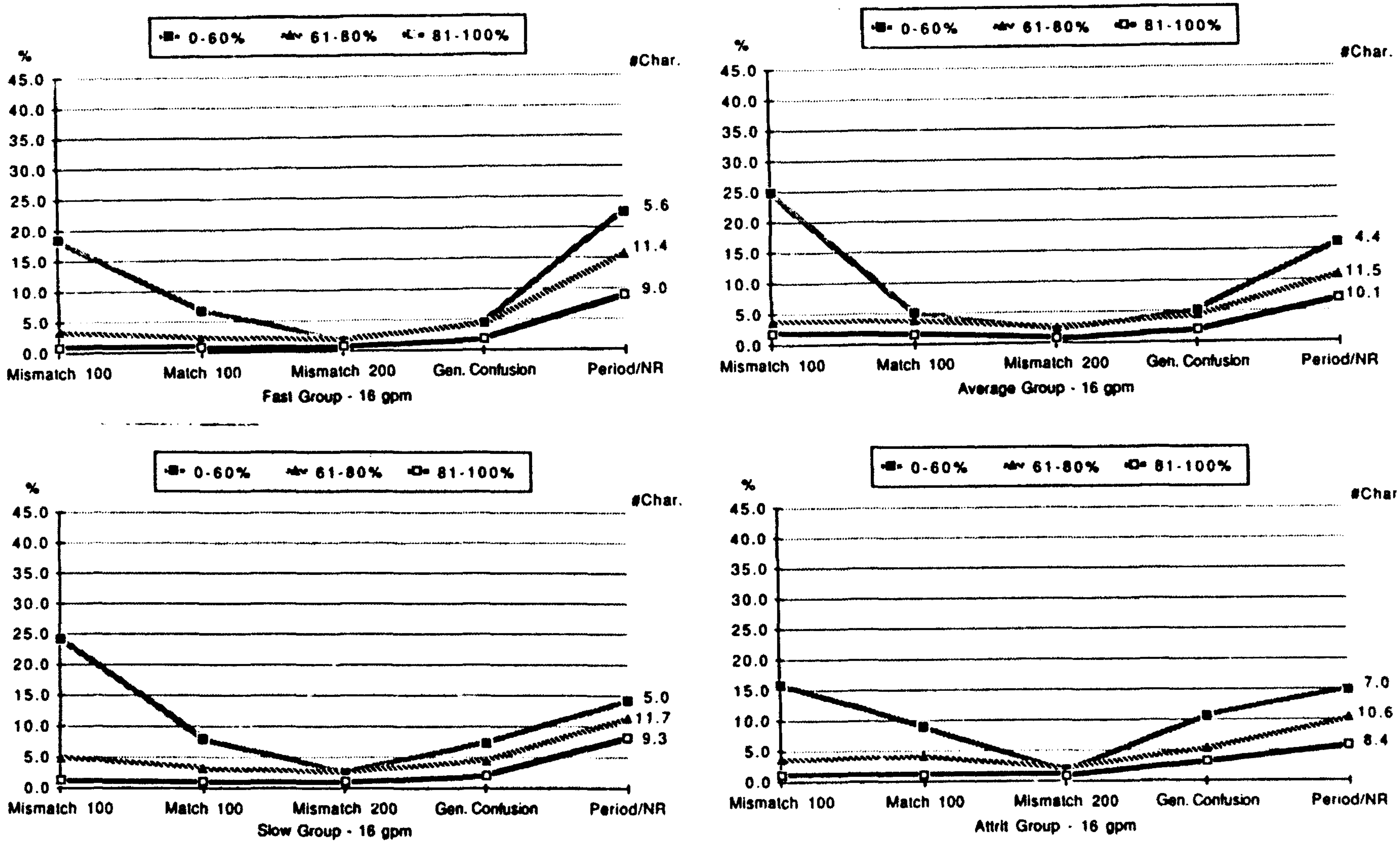


Figure 18. Frequency of Error Types Averaged Over Percent of Times Each Character Was Sent With Characters Classified Into Three Levels of Accuracy - 16 gpm

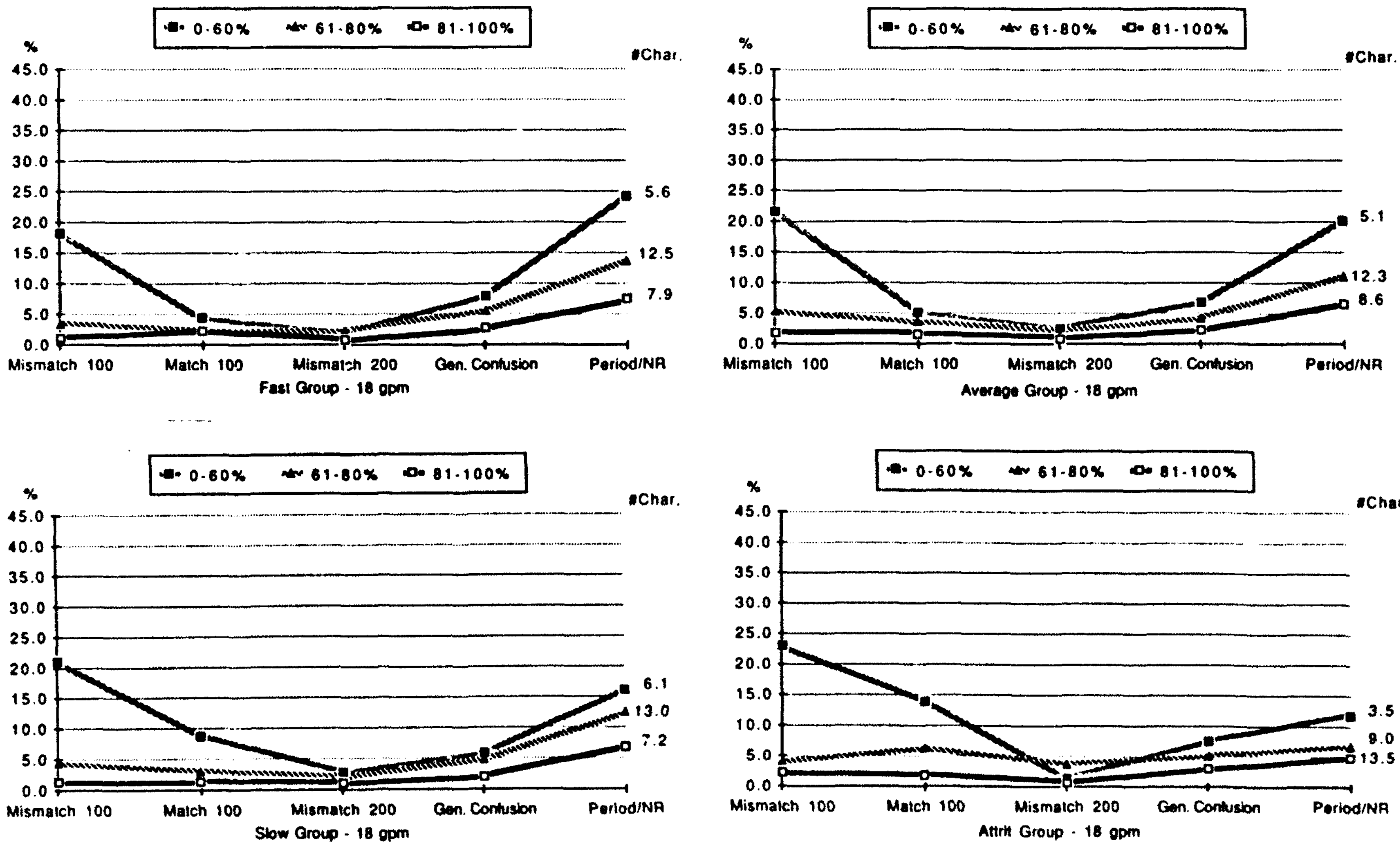


Figure 19. Frequency of Error Types Averaged Over Percent of Times Each Character Was Sent With Characters Classified into Three Levels of Accuracy - 18 gpm

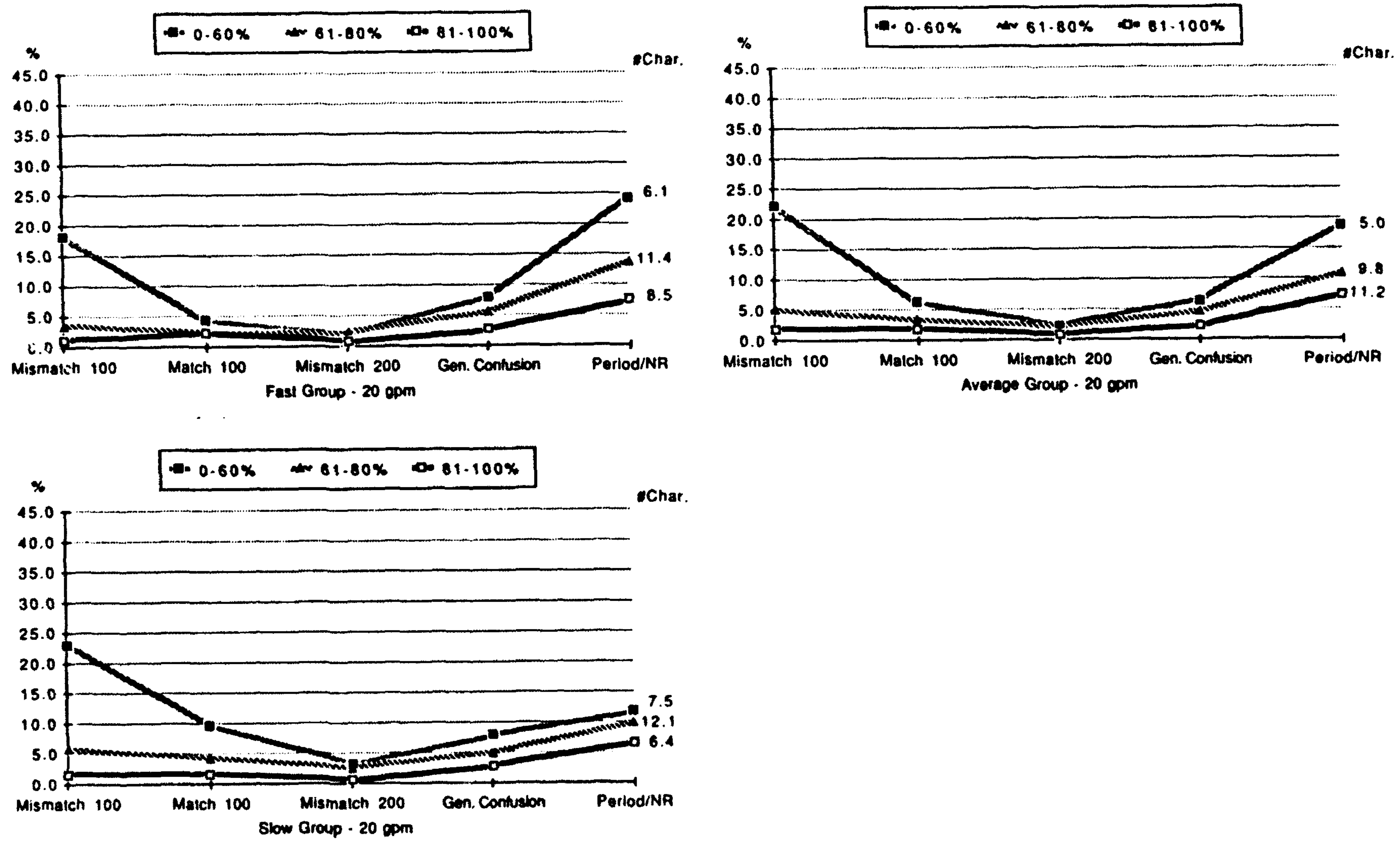


Figure 20. Frequency of Error Types Averaged Over Percent of Times Each Character Was Sent With Characters Classified Into Three Levels of Accuracy - 20 gpm

The Attrit group is less consistent in showing a higher frequency of period/no response rates compared to other error types at the two highest levels of accuracy. At the 0-60% level of accuracy Mismatch-100 errors are the most frequent error type from 10 through 18 gpm.

Match-100 msec and General Confusion errors are generally about equal in frequency ranging from around 5 to 10% at the 0-60% level of accuracy for each group of subjects. Mismatch-200 msec errors show the lowest frequency rates for each of the four groups of subjects at all speed levels.

## DISCUSSION AND CONCLUSIONS

Reasons advanced for occurrence of substitution errors, especially the Mismatch-100 msec type, has prominently included rushing response to beat the next signal. This reasoning appears plausible when considering the Mismatch-100 msec errors. For example, the signal for the letter C (dah di dah dit) is sent and the student responds with the letter K (dah di dah). Response time data reported here appears to contradict this notion. These data show error response times generally longer than response times for correct responses. In fact, characters having mean correct responses in the 81-100% range have the shortest response times across all speed groups and for each subject group.

One alternative interpretation is that the student is shifting attention from reception of the signal before it is completed in favor of processing to identify the character it represents. This views the student erring by accepting an anticipatory closure for the signal being sent rather than rushing the motor response to beat the next signal. However, using this interpretaton it is not clear why response time would be longer as these data show, rather than shorter.

Another alternative interpretation of the occurrence of substitution errors comes from the observation of the high period/no response errors for the Fast group. This is the only group for which period/no response has a higher frequency than the other error types at each level of accuracy and across all speed levels. Use of the period/no reponse may represent an "in doubt don't respond" strategy. Whether or not this is a deliberately chosen strategy is not known. The Fast group's higher frequency in using the period/no response certainly precludes occurrence of substitution errors. It also raises the question of whether or not this strategy relates to faster progress through training. If so, it may reflect an ability to more accurately detect and recognize the pattern of a signal and in so doing separate "know" from "aren't sure" or "don't know."

If attrits or slower students have lower skill in detecting-recognizing signal patterns, they have greater difficulty in separating "know" from "aren't sure" or "don't know". As a result, they are less likely to respond with period/no response and are more likely to make a substitution error by imposing a pattern on the signal.

This could be explored experimentally by setting conditions under which subjects drawn to represent different rates of progress through training are rewarded for accuracy and instructed to use period/no response any time they "don't know" or "aren't sure". If use of the period/no response reflects an ability factor or skill in detecting and recognizing pattern of signals it would be expected that the slower groups would have higher rates of substitution errors and lower rates of period/no response errors.

Errors which add or shorten elements in the signal, as well as those that interchange dits for dahs and dahs for dits are all thought to reflect a failure in pattern detection. This interpretation appears more consistent with the longer response time for substitution errors if it is assumed that defective pattern detection results in longer processing time consumed in attempting to identify a pattern for the signal and associate this with a character. In other words, it assumes a muddled rather than clear auditory perception of the signal's pattern, resulting in uncertainty during the recognition process which creates the longer response time. This interpretation argues that the most difficult task is that of learning to identify patterns of signals as time available decreases rather than that of learning the signal-character association.

Basic Morse code training is unlike other military job training in that it focuses on repetitive practice, 6 hours a day, to develop one complex skill, receiving Morse code. The practice trial unit during this training is a 250 character block. As transmission speed increases during the speed building phase the number of blocks received during a training day increases as well as the number of days to pass the speed group (Figure 4). For example, starting at 6 gpm, the student would receive about 36 blocks in a training day consisting of 6 fifty minute periods. By the time the student reaches

20 gpm, 120 blocks would be received during a training day. Thus, given the differences among students in the number of days to pass a given speed level there is a tremendous range in amount of practice students have in a given speed group on a given day.

Without regard to group, the graduates ranged from 36 to 155 days in training. The Attrit group ranged from 50 to 131 days in training before attriting. The classification of students into the 3 groups who graduated (Fast, Average, and Slow groups) based on number of days to graduate is assumed to reflect skill in learning code. Thus, greater amounts of practice means lesser skill in learning to get to the same accuracy criterion. One reason we may not have found clearer differences in performance between graduates and attrits is the lack of control we had over training time in speed group when they reported for each research session. In the operational training setting this type of control could not be provided.

## SUMMARY

Data obtained from early research on initial learning and speed building phases show that rank order of difficulty for characters is *not correlated across phases.* This approach to error analysis focuses on the associative bond between the auditory signal and the character. Shifting focus to the characteristics of the signal sent and those of the signal for the error response show that the most frequent type of auditory-perceptual error differs for these two phases. During the initial learning phase the predominate characteristic of the signal sent and the signal for the error response is the correct matching of the number of elements. In contrast, during the speed building phase this shifts to a mismatch of the number of elements.

A three factor framework was developed to classify errors focusing on characteristics of the signals likely to have implications for the requirements placed on the students' auditory-perceptual processes. The three factors were a match or mismatch of the number of elements, number of elements misperceived, and, absolute difference in time durations of the signal sent and the signal incorrectly identified.

Performance in receiving Morse code was obtained from 46 volunteer Basic Morse code students while in the speed building phase of the training. Students were classified into four groups; the

Attrits, and three groups (Fast, Average, and Slow) based on the number of days to graduation from Basic Morse Code training.

Overall mean percent correct scores are very similar for the four groups at each of the speed levels. Of the four groups the Fast Group tends to have the longest overall mean correct response times. All ability groups show a similar pattern in reduction of response times as gpm speeds of transmission increase.

Mean percent correct and response time for each letter were classified into three levels of accuracy for each group of students. The trend for all ability groups is for their highest level of accuracy to have the shortest response time and the mean response time for correct responses increases as the accuracy level decreases. Thus, the longest response times for correct responses are generally for signals that students seldom get correct. The difference between correct and error response times tends to be largest at the highest accuracy level with error response time the longest. There is little or no difference between response times for correct and error responses at the lowest accuracy level.

Analysis of error types for the four groups shows that the Fast group is the only one of the four in which period/no response has a higher frequency than the other error types at each of the 3 levels of accuracy and across all speed levels. It is suggested that occurrence of period/no response errors may reflect a "don't know" response to a muddled auditory perception of the signal's pattern. Greater use of period/no response as opposed to substitution errors may reflect greater ability or skill in detecting a defective perception of the signal's pattern. A research approach is presented for testing this hypothesis.

Number of days to graduate is assumed to reflect skill in learning code. Thus, greater amounts of practice means lesser skill in learning code to get to a common accuracy criterion. One important factor necessary for interpretation of results from future research on Morse code learning is the ability to control for cumulative training time and time in speed group for each set of data collected. Inability to exert this type of control during collection of data presented in this report may be the major reason fewer differences were found among groups.

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## APPENDIX A

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# APPENDIX B: MORSE CODE FOR LETTERS, NUMBERS, AND SPECIAL CHARACTERS

| Character - Code | | msec |
|---|---|---|
| E | DIT | 50 |
| T | DAH | 150 |
| I | DI DIT | 150 |
| A | DI DAH | 250 |
| N | DAH DIT | 250 |
| S | DI DI DIT | 250 |
| H | DI DI DI DIT | 350 |
| M | DAH DAH | 350 |
| U | DI DI DAH | 350 |
| D | DAH DI DIT | 350 |
| R | DI DAH DIT | 350 |
| W | DI DAH DAH | 450 |
| G | DAH DAH DIT | 450 |
| K | DAH DI DAH | 450 |
| V | DI DI DI DAH | 450 |
| B | DAH DI DI DIT | 450 |
| L | DI DAH DI DIT | 450 |
| F | DI DI DAH DIT | 450 |
| O | DAH DAH DAH | 550 |
| Z | DAH DAH DI DIT | 550 |
| X | DAH DI DI DAH | 550 |
| C | DAH DI DAH DIT | 550 |
| P | DI DAH DAH DIT | 550 |
| J | DI DAH DAH DAH | 650 |
| Y | DAH DI DAH DAH | 650 |
| Q | DAH DAH DI DAH | 650 |

| Numbers - Code | | msec |
|---|---|---|
| 1 | DI DAH DAH DAH DAH | 850 |
| 2 | DI DI DAH DAH DAH | 750 |
| 3 | DI DI DI DAH DAH | 650 |
| 4 | DI DI DI DI DAH | 550 |
| 5 | DI DI DI DI DI | 450 |
| 6 | DAH DI DI DI DIT | 550 |
| 7 | DAH DAH DI DI DIT | 650 |
| 8 | DAH DAH DAH DI DIT | 750 |
| 9 | DAH DAH DAH DAH DIT | 850 |
| 0 | DAH DAH DAH DAH DAH | 950 |

| Special Characters | Code | msec |
|---|---|---|
| BARD ECHO | DI DI DAH DI DIT | 550 |
| BARD UNIFORM | DI DI DAH DAH | 550 |
| BARD ALFA | DI DAH DI DAH | 550 |
| BARD OSCAR | DAH DAH DAH DIT | 650 |
| BARD HOTEL | DAH DAH DAH DAH | 750 |

# APPENDIX C

## Classification of Error Pairs for the Alphabet and Five Special Characters

Classification of Characters Into Types of Errors Mismatching Number of Elements in Signal

| | A | B | C | D | E |
|---|---|---|---|---|---|
| 1 | Mismatch-GC-0 | Mismatch-100 | Mismatch-GC-100 | Mismatch-200 | Mismatch-GC-200+ |
| 2 | B - G | A - T | B - U | A - E | B - A |
| 3 | B - K | B - D | B - R | B - S | B - E |
| 4 | B - W | C - K | B - O | C - R | B - I |
| 5 | C - O | D - N | B - M | C - D | B - N |
| 6 | D - M | F - U | C - W | D - I | B - T |
| 7 | F - G | F - R | C - G | F - S | C - A |
| 8 | F - K | G - M | D - A | G - N | C - E |
| 9 | F - W | H - S | F - D | J - W | C - I |
| 10 | H - D | I - E | F - O | K - A | C - M |
| 11 | H - M | J - O | F - M | K - N | C - N |
| 12 | H - R | K - M | H - A | L - S | C - S |
| 13 | H - U | L - R | H - G | M - T | C - T |
| 14 | I - T | L - D | H - K | N - E | C - U |
| 15 | L - G | N - T | H - N | O - M | D - E |
| 16 | L - K | P - G | H - W | P - R | D - T |
| 17 | L - W | P - W | L - M | Q - G | F - A |
| 18 | P - O | Q - O | L - O | Q - K | F - E |
| 19 | R - M | R - A | L - U | R - I | F - I |
| 20 | S - A | R - N | P - K | U - I | F - N |
| 21 | S - N | S - I | S - M | V - S | F - T |
| 22 | U - M | U - A | S - T | W - A | G - A |
| 23 | V - G | V - U | U - N | X - D | G - E |
| 24 | V - K | W - M | V - D | X - U | G - I |
| 25 | V - W | X - K | V - O | Y - K | G - T |
| 26 | X - O | Y - O | V - M | Y - W | H - E |
| 27 | Z - O | Z - G | V - R | Z - D | H - I |
| 28 | BARD A - O | BARD A - K | X - G | BARD A - R | H - O |
| 29 | BARD A - BARD E | BARD E - F | X - W | BARD H - O | H - T |
| 30 | BARD E - C | BARD E - L | Z - K | BARD O - G | J - A |
| 31 | BARD E - O | BARD O - O | Z - W | BARD U - U | J - D |
| 32 | BARD E - P | BARD U - W | BARD A - G | | J - E |
| 33 | BARD E - X | | BARD A - W | | J - G |
| 34 | BARD E - Z | | BARD E - B | | J - I |
| 35 | BARD U - O | | BARD E - G | | J - K |
| 36 | BARD U - BARD E | | BARD E - J | | J - M |
| 37 | | | BARD E - K | | J - N |
| 38 | | | BARD E - Q | | J - R |
| 39 | | | BARD E - V | | J - S |
| 40 | | | BARD E - W | | J - T |
| 41 | | | BARD E - Y | | J - U |
| 42 | | | BARD E - BARD O | | K - E |
| 43 | | | BARD U - G | | K - I |
| 44 | | | BARD U - K | | K - T |
| 45 | | | | | L - A |
| 46 | | | | | L - E |
| 47 | | | | | L - I |
| 48 | | | | | L - N |
| 49 | | | C - 2 | | |

Classification of Characters Into Types of Errors Mismatching Number of Elements In Signal

| | F | G | H |
|---|---|---|---|
| 1 | Mismatch | -GC-200+, Continued | |
| 2 | L - T | X - S | BARD H - K |
| 3 | M - E | X - T | BARD H - M |
| 4 | O - A | Y - A | BARD H - N |
| 5 | O - E | Y - D | BARD H - R |
| 6 | O - I | Y - E | BARD H - S |
| 7 | O - N | Y - G | BARD H - T |
| 8 | O - T | Y - I | BARD H - U |
| 9 | P - A | Y - M | BARD H - W |
| 10 | P - D | Y - N | BARD H - BARD E |
| 11 | P - E | Y - R | BARD O - A |
| 12 | P - I | Y - S | BARD 0 - D |
| 13 | P - M | Y - T | BARD O - E |
| 14 | P - N | Y - U | BARD O - I |
| 15 | P - S | Z - A | BARD O - K |
| 16 | P - T | Z - E | BARD O - M |
| 17 | P - U | Z - I | BARD O - N |
| 18 | Q - A | Z - M | BARD O - R |
| 19 | Q - D | Z - N | BARD O - S |
| 20 | Q - E | Z - R | BARD O - T |
| 21 | Q - I | Z - S | BARD O - U |
| 22 | Q - M | Z - T | BARD O - W |
| 23 | Q - N | Z - U | BARD U - A |
| 24 | Q - R | BARD A - A | BARD U - D |
| 25 | Q - S | BARD A - D | BARD U - E |
| 26 | Q - T | BARD A - E | BARD U - I |
| 27 | Q - U | BARD A - I | BARD U - M |
| 28 | Q - W | BARD A - M | BARD U - N |
| 29 | R - E | BARD A - N | BARD U - R |
| 30 | R - T | BARD A - S | BARD U - S |
| 31 | S - E | BARD A - T | BARD U - T |
| 32 | U-E | BARD A - U | |
| 33 | U - T | BARD E - A | |
| 34 | V - A | BARD E - D | |
| 35 | V - E | BARD E - E | |
| 36 | V - I | BARD E - H | |
| 37 | V - N | BARD E - I | |
| 38 | V - T | BARD E - M | |
| 39 | W - E | BARD E - N | |
| 40 | W - I | BARD E - R | |
| 41 | W - N | BARD E - S | |
| 42 | W - T | BARD E - T | |
| 43 | X - A | BARD E - U | |
| 44 | X - E | BARD H - A | |
| 45 | X - I | BARD H - D | |
| 46 | X - M | BARD H - E | |
| 47 | X - N | BARD H - G | |
| 48 | X - R | BARD H - I | |
| 49 | | | C - 3 |

Classification of Characters Into Types of Errors Matching Number of Elements in Signal

| | A | B | C | D | E |
|---|---|---|---|---|---|
| 1 | Match-GC-Zero | Match | -100 | Match-GC-100 | Match-GC-200+ |
| 2 | A - N | First Element | Second Element | C - L | C-H |
| 3 | C - Z | B - H | G - D | C - V | J-B |
| 4 | F - B | C - F | L - H | G - U | J-F |
| 5 | F - L | D - S | O - K | J - C | J-H |
| 6 | J - Q | G - R | P - F | J - X | J-L |
| 7 | J - Y | K - U | Q - X | J - Z | J-V |
| 8 | K - G | M - A | R - S | K - R | G-S |
| 9 | L - B | N - I | W - U | P - B | K-S |
| 10 | P - C | O - W | Z - B | P - V | M-I |
| 11 | P - X | X - V | J - BARD U | Q - C | O-D |
| 12 | P - Z | Z - L | BARD A - V | Q - P | O-R |
| 13 | R - D | Q - BARD A | BARD H - Y | W - D | O-S |
| 14 | U - D | Y - BARD U | BARD O - C | X - F | O-U |
| 15 | U - R | BARD H - J | | X - L | P-H |
| 16 | V - B | BARD O - P | | Y - P | Q-B |
| 17 | V - F | | | Y - Z | Q-F |
| 18 | V - L | Third Element | Last Element | Z - F | Q-H |
| 19 | W - G | C - B | A - I | Z - V | Q-L |
| 20 | W - K | F - H | J - P | Q - BARD U | Q-V |
| 21 | X - C | P - L | K - D | Y - BARD A | W-S |
| 22 | X - Z | Y - X | M - N | BARD A - B | X-H |
| 23 | Y - Q | J - BARD A | O - G | BARD A - F | Y-B |
| 24 | BARD A - C | BARD H - Q | Q - Z | BARD O - X | Y-F |
| 25 | BARD A - P | BARD O - Z | T - E | BARD U - B | Y-H |
| 26 | BARD A - X | BARD U - V | U - S | BARD U - L | Y-L |
| 27 | BARD A - Z | | V - H | BARD O - BARD A | Y-V |
| 28 | BARD O - J | | W - R | BARD O - BARD U | Z-H |
| 29 | BARD O - Q | | X - B | | BARD A - H |
| 30 | BARD O - Y | | Y - C | | BARD H - B |
| 31 | BARD U - C | | BARD A - L | | BARD H - C |
| 32 | BARD U - P | | BARD U - F | | BARD H - F |
| 33 | BARD U - X | | BARD H - BARD O | | BARD H - H |
| 34 | BARD U - Z | | | | BARD H - L |
| 35 | BARD U - BARD A | | | | BARD H - P |
| 36 | | | | | BARD H - V |
| 37 | | | | | BARD H - X |
| 38 | | | | | BARD H - Z |
| 39 | | | | | BARD O - B |
| 40 | | | | | BARD O - F |
| 41 | | | | | BARD O - H |
| 42 | | | | | BARD O - L |
| 43 | | | | | BARD O - V |
| 44 | | | | | BARD U - H |
| 45 | | | | | BARD H - BARD A |
| 46 | | | | | BARD H - BARD U |
| 47 | | | | | |
| 48 | | | C - 4 | | |